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SIR;

CERTIFIED TRANSLATION

I, Takahisa SATOH, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 2000-189730, filed on June 20, 2000.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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[TITLE OF THE INVENTION] Optical Device, Method for Production of Optical Device, and Optical System

[CLAIMS]

[Claim 1]

An optical device comprising

a convex lens formed with a convex curved face and

a base material closely contacting the convex curved face of the convex lens, wherein

the base material has first and second faces facing each other, a concave curved face closely contacting the convex curved face being formed in the first face, and a hole communicating with the second face being formed from a deep side of the concave curved face, and

part of the convex curved face of the convex lens is exposed in the hole of the base material.

[Claim 2]

An optical device as set forth in claim 1, wherein

the convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded or substantially surrounded by a flat face and the convex curved face facing this flat face, and

an optical axis of the convex lens or an extension thereof passes through the hole.

[Claim 3]

An optical device as set forth in claim 2, wherein the second face of the base material is flat or substantially flat and parallel or substantially parallel to the flat face of the convex lens.

[Claim 4]

An optical device as set forth in claim 2, wherein the area around the concave curved face in the first face of the base material is flat or substantially flat and parallel or substantially parallel to the flat face of the convex lens.

[Claim 5]

An optical device as set forth in claim 2, wherein the area around the concave curved face in the first face of the base material is flat or substantially flat and located in an identical plane or substantially identical plane

[Claim 6]

An optical device as set forth in claim 2, wherein

the hole has a rotationally symmetric or substantially rotationally symmetric shape,

the rotational symmetry axis of the hole and the optical axis of the convex lens coincide or substantially coincide, and

the concave curved face forms an annular inclined face.

[Claim 7]

An optical device as set forth in claim 1, wherein the material of the convex lens can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 8]

An optical system comprising first and second optical devices, wherein

the first optical device has

a first convex lens formed with a convex curved face and

a first base material with the convex curved face of the first convex lens bonded thereto;

the first base material has first and second faces facing each other, a concave curved face closely contacting the convex curved face being formed in the first face, and a hole communicating with the second face being formed from a deep side of the concave curved face; and

part of the convex curved face of the first convex lens is exposed in the first hole of the first base material; and

the second optical device has

a second convex lens with the convex curved face formed thereon and

a second base material with the convex curved face of the second convex lens bonded thereto;

the second base material has third and fourth faces facing each other, a concave curved face closely contacting the convex curved face of the second convex lens being formed in the third face, and the first and second optical devices being bonded so that the optical axes of the first and second convex lenses coincide or substantially coincide.

[Claim 9]

An optical system as set forth in claim 8, wherein the first face of the first base material and the fourth face of the second base material are bonded.

[Claim 10]

An optical system as set forth in claim 8, wherein the second face of the first base material and the third face of the second base material are bonded.

[Claim 11]

An optical system as set forth in claim 8, wherein

the first convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face facing this flat face, and

the optical axis of the first convex lens or the extension thereof passes through the first hole.

[Claim 12]

An optical system as set forth in claim 11, wherein

the second face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex curved face, and

the area around the concave curved face in the first face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex lens.

[Claim 13]

An optical system as set forth in claim 11, wherein

the second face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex curved face, and

the area around the concave curved face in the first face of the first base material is flat or substantially flat and located in the identical plane or substantially identical plane to the flat face of the first convex lens.

[Claim 14]

An optical system as set forth in claim 11, wherein

the first hole has a rotationally symmetric or substantially rotationally symmetric shape,

the rotational symmetry axis of the first hole and the optical axis of the first convex lens coincide or substantially coincide, and

the concave curved face of the first base material forms an annular inclined face.

[Claim 15]

An optical system as set forth in claim 8, wherein

in the second base material, a second hole communicating with the fourth face is formed from the deep side of the concave curved face closely contacting the convex curved face of the second convex lens, and

part of the convex curved face of the second convex lens is exposed in the second hole of the second base material.

[Claim 16]

An optical system as set forth in claim 15, wherein

the second convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face facing this flat face, and

the optical axis of the second convex lens or the extension thereof passes through the second hole.

[Claim 17]

An optical system as set forth in claim 16, wherein

the fourth face of the second base material is flat or substantially flat and parallel or substantially parallel to the flat face of the second convex curved face, and

the area around the concave curved face in the third face of the second base material is flat or substantially flat and parallel or substantially parallel to the flat face of the second convex lens.

[Claim 18]

An optical system as set forth in claim 16, wherein

the fourth face of the second base material is flat or substantially flat and parallel or substantially parallel to the flat face of the second convex curved face, and

the area around the concave curved face in the third face of the second base material is flat or substantially flat and located in the identical plane or substantially identical plane to the flat face of the second convex lens.

[Claim 19]

An optical system as set forth in claim 16, wherein

the second hole has a rotationally symmetric or substantially rotationally symmetric shape,

the rotational symmetry axis of the second hole and

the optical axis of the second convex lens coincide or substantially coincide, and

the concave curved face of the second base material forms an annular inclined face.

[Claim 20]

An optical system as set forth in claim 8, wherein the material of the first and/or second convex lens is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 21]

An optical system as set forth in claim 8, wherein

the first convex lens is larger than the second convex lens,

the first face of the first base material and the fourth face of the second base material are bonded, and

a solid immersion lens is comprised by the first and second optical devices.

[Claim 22]

An optical system as set forth in claim 21, comprising a slider of an optical head attached to a swing arm.

[Claim 23]

An optical system as set forth in claim 22, wherein

the material of the second base material is aluminum oxide or silicon oxide.

[Claim 24]

A method for production of an optical device having a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising

a step of using a metallic mold formed with a projection projecting out into a cavity to mold a base material formed with a concavity reproducing the shape of the projection,

a step of filling an optical material in the concavity of the molded base material,

a step of flattening the surface of the optical material filled in the concavity to form the convex lens, and

a step of forming a hole so that part of the convex curved face closely contacting the concavity in the convex lens is exposed in the base material.

[Claim 25]

A method of production of an optical device as set forth in claim 24, further comprising a step of polishing the base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[Claim 26]

A method of production of an optical device as set forth in claim 25, wherein

the step of forming the hole in the base material has

a step of forming a resist film having a window on the flat face of the base material formed in the step of polishing the base material,

a step of forming a hole corresponding to the window in the base material by etching, and

a step of removing the resist film from the base material.

[Claim 27]

A method of production of an optical device as set forth in claim 26, wherein the window has a circular or substantially circular shape.

[Claim 28]

A method of production of an optical device as set forth in claim 25, wherein

the step of filling the optical material has

a step of forming a coating film covering the surface of the concavity of the moled base material and

a step of filling a optical material in the concavity formed with the coating film,

the step of forming the hole in the base material has

a step of forming a resist film having a window on the flat face of the base material formed in the step of polishing the base material,

a step of forming a hole reaching the coating film from the window in the base material by etching,

a step of removing the resist film from the base material formed with the hole, and

a step of removing the part of the coating film exposed in the hole.

[Claim 29]

A method of production of an optical device as set forth in claim 28, wherein the window has a circular or substantially circular shape.

[Claim 30]

A method of production of an optical device as set forth in claim 24, wherein

the projection has a rotationally symmetric or substantially rotationally symmetric shape, and

in the step of forming the convex lens, the surface of the optical material is polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity with the shape of the projection transferred thereto is formed.

[Claim 31]

A method of production of an optical device as set

forth in claim 30, wherein the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or substantially arc.

[Claim 32]

A method of production of an optical device as set forth in claim 24, wherein the optical material is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 33]

A method for production of an optical device having a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising

a step of forming a first resist film having a first window in the flat face of the base material,

a step of forming a concavity corresponding to the first window in the base material by etching,

a step of removing the first resist film from the base material formed with the concavity,

a step of filling an optical material in the concavity of the base material from which the first resist film is removed,

a step of flattening the surface of the optical material filled in the concavity to form the convex lens,

and

a step of forming a hole whereby part of the convex curved face closely contacting the concavity in the convex lens is exposed in the base material.

[Claim 34]

A method of production of an optical device as set forth in claim 33, further comprising a step of polishing the base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[Claim 35]

A method of production of an optical device as set forth in claim 34, wherein

the step of forming the hole in the base material has

a step of forming a second resist film having a second window in the flat face of the base material formed in the step of polishing the base material,

a step of forming a hole corresponding to the second window in the base material by etching, and

a step of removing the second resist film from the base material formed with the hole.

[Claim 36]

A method of production of an optical device as set forth in claim 35, wherein the second window has a

circular or substantially circular shape.

[Claim 37]

A method of production of an optical device as set forth in claim 34, wherein

the step of filling the optical material has

a step of forming a coating film covering the surface of the concavity of the base material from which the first resist film has been removed and

a step of filling an optical material in the concavity formed with the coating film, and

the step of forming the hole in the base material has

a step of forming a second resist film having a second window in the flat face of the base material formed in the step of polishing the base material,

a step of forming a hole reaching the coating film from the second window in the base material by etching,

a step of removing the second resist film from the base material formed with the hole, and

a step of removing a part exposed in the hole in the coating film.

[Claim 38]

A method of production of an optical device as set forth in claim 37, wherein the second window has a circular or substantially circular shape.

[Claim 39]

A method of production of an optical device as set forth in claim 33, wherein

the first window is circular or substantially circular,

the concavity has a rotationally symmetric or substantially rotationally symmetric shape, and

in the step of forming the convex lens, the surface of the optical material is polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity is formed.

[Claim 40]

A method of production of an optical device as set forth in claim 39, wherein the shape of the surface of the concavity when the concavity is cut along its symmetry axis is an arc or substantially arc.

[Claim 41]

A method of production of an optical device as set forth in claim 33, wherein the optical material is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[Claim 42]

A method for production of an optical device having

a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising

a step of forming on a second base material provided with a projection and having a flat area around the projection a first base material made of a layer burying the projection,

a step of flattening the surface of the first base material to form a flat face and bonding the related flat face to a third base material,

a step of removing the second base material from the first base material bonded to the third base material to expose the concavity with the shape of the projection transferred thereto in the first base material,

a step of filling an optical material in the exposed concavity of the first base material,

a step of flattening the surface of the optical material filled in the concavity to form the convex lens, and

a step of forming holes whereby part of the convex curved face closely contacting the concavity in the convex lens is exposed in the first and third base materials.

[Claim 43]

A method of production of an optical device as set forth in claim 42, further comprising a step of polishing

the third base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[Claim 44]

A method of production of an optical device as set forth in claim 43, wherein

the step of forming the holes in the first and third base materials has

a step of forming a resist film having a window in the flat face of the third base material formed in the step of polishing the third base material,

a step of forming holes corresponding to the windows in the first and third base materials by etching, and

a step of removing the resist films from the first and third base materials formed with the holes formed.

[Claim 45]

A method of production of an optical device as set forth in claim 44, wherein the windows have circular or substantially circular shapes.

[Claim 46]

A method of production of an optical device as set forth in claim 43, wherein

the step of filling the optical material has

a step of forming a coating film covering the surface of the exposed concavity of the first base

material and

a step of filling the optical material in the concavity formed with the coating film, and

the step of forming the hole in the base material has

a step of forming a resist film having a window in the flat face of the third base material formed in the step of polishing the third base material,

a step of forming holes reaching the coating film from the window in the first and third base materials by etching,

a step of removing the resist films from the first and third base materials formed with the holes formed, and a step of removing the part exposed in the hole in the coating film.

[Claim 47]

A method of production of an optical device as set forth in claim 46, wherein the windows have circular or substantially circular shapes.

[Claim 48]

A method of production of an optical device as set forth in claim 42, wherein

the projection has a rotationally symmetric or substantially rotationally symmetric shape, and

in the step of forming the convex lens, the surface

of the optical material is polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity with the shape of the projection transferred thereto is formed.

[Claim 49]

A method of production of an optical device as set forth in claim 48, wherein the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or substantially arc.

[Claim 50]

A method of production of an optical device as set forth in claim 42, wherein the first and third base materials are made of an identical material.

[Claim 51]

A method of production of an optical device as set forth in claim 42, wherein the optical material is titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[DETAILED DESCRIPTION OF THE INVENTION]

[0001]

[Technical Field of the Invention]

The present invention relates to an optical device and a method for production of the same and to an optical

system having the optical device.

[0002]

[Prior Art]

When producing a lens, the following first to third methods of production have been known.

The first method of production is a method of filling an optical material in a metallic mold machined to an intended lens shape and producing the lens by simple molding.

The second method of production is a method of utilizing reactive ion etching (RIE) or other etching and using a photoresist or the like as a mask (etching mask) to etch an optical material to a predetermined shape to thereby produce a lens made of the related optical material.

The third method of production is a method of mechanically polishing a base material made of an optical material to the lens shape to produce the lens.

[0003]

[Problems to be Solved by the Invention]

In the conventional first method of production, that is, the method using simple molding, it is difficult to produce a small sized lens having a large numerical aperture, so it is difficult to reduce the lens diameter to 1 mm or less.

In the conventional second method of production, that is, the method using RIE or other etching, the optical material is limited, so it is difficult to use a material having a high refractive index and it is difficult to realize a lens having a large numerical aperture NA.

In the conventional third method of production, it is difficult to manufacture a small sized lens.

[0004]

If increasing the numerical aperture of the lens, it is possible to make the size of a light spot created after passing through the lens small. It is desirable from the viewpoint of increase of the capacity of an optical disc to enlarge the numerical aperture NA of the lens (object lens) of an optical head.

Also, lenses and other optical devices are being used for various optical apparatuses. Reduction of the size of the optical devices is desirable from the viewpoint of the reduction of size of the optical apparatuses.

[0005]

In order to realize an optical device having a large numerical aperture, a large refractive index of the optical material is effective.

As an optical material having a high refractive

index in a region of visible light, there are titanium oxide, tantalum oxide, niobium oxide, gallium phosphate (gallium phosphorus), gallium nitride, silicon nitride, etc.

However, it is difficult to machine these materials to small sized lenses having a large numerical aperture in the prior art.

[0006]

Also, many conventional lenses have irregular shapes. In order to align a plurality of lenses of such irregular shapes, high precision positioning in three-dimensional directions is necessary, so the load of the alignment work is large.

Also, when comprising a flying head (floating head) consisting of an optical head mounted on a swing arm, the optical head can be prepared by separately preparing a slider and the lens and attaching them at a high precision, but in this case, the load of the attachment work and accordingly the load of preparation of the optical head is large.

[0007]

A first object of the present invention is to provide a method of production of an optical device capable of creating an optical device having a small sized convex lens, a second object is to provide a method

of production of an optical device capable of creating an optical device having a convex lens with a small size and a large numerical aperture, a third object is to provide an optical device which can be created from the method of production, and a fourth object is to provide an optical system having the related optical device.

[0008]

[Means for Solving the Problem]

An optical device according to the present invention has a convex lens formed with a convex curved face and a base material closely contacting the convex curved face of the convex lens, wherein the base material has first and second faces facing each other, a concave curved face closely contacting the convex curved face is formed in the first face, and a hole communicating with the second face is formed from a deep side of the concave curved face to, and part of the convex curved face of the convex lens is exposed in the hole of the base material.

[0009]

In the optical device according to the present invention, preferably the convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded or substantially surrounded by a flat face and the convex curved face facing this flat face, and an optical axis of the convex lens or an extension thereof

passes through the hole.

[0010]

In the optical device according to the present invention, more preferably the second face of the base material is flat or substantially flat and parallel or substantially parallel to the flat face of the convex lens.

[0011]

In the optical device according to the present invention, more preferably the area around the concave curved face in the first face of the base material is flat or substantially flat and parallel or substantially parallel to the flat face of the convex lens.

[0012]

In the optical device according to the present invention, more preferably the area around the concave curved face in the first face of the base material is flat or substantially flat and located in an identical plane or substantially identical plane

[0013]

In the optical device according to the present invention, more preferably the hole has a rotationally symmetric or substantially rotationally symmetric shape, the rotational symmetry axis of the hole and the optical axis of the convex lens coincide or substantially

coincide, and the concave curved face forms an annular inclined face.

[0014]

In the optical device according to the present invention, for example, the material of the convex lens can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0015]

An optical system according to the present invention is an optical system comprising first and second optical devices, wherein the first optical device has a first convex lens formed with a convex curved face and a first base material with the convex curved face of the first convex lens bonded thereto; the first base material has first and second faces facing each other, a concave curved face closely contacting the convex curved face being formed in the first face, and a hole communicating with the second face being formed from a deep side of the concave curved face; and part of the convex curved face of the first convex lens is exposed in the first hole of the first base material; and the second optical device has a second convex lens with the convex curved face formed thereon and a second base material with the convex

curved face of the second convex lens bonded thereto; the second base material has third and fourth faces facing each other, a concave curved face closely contacting the convex curved face of the second convex lens being formed in the third face, and the first and second optical devices being bonded so that the optical axes of the first and second convex lenses coincide or substantially coincide.

[0016]

In the optical system according to the present invention, for example, also a configuration may be used wherein the first face of the first base material and the fourth face of the second base material are bonded.

In the optical system according to the present invention, for example, also a configuration may be used wherein the second face of the first base material and the third face of the second base material are bonded.

[0017]

In the optical system according to the present invention, preferably the first convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face facing this flat face, and the optical axis of the first convex lens or the extension thereof passes through the first hole.

[0018]

In the optical system according to the present invention, more preferably the second face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex curved face, and the area around the concave curved face in the first face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex lens.

[0019]

In the optical system according to the present invention, more preferably the second face of the first base material is flat or substantially flat and parallel or substantially parallel to the flat face of the first convex curved face, and the area around the concave curved face in the first face of the first base material is flat or substantially flat and located in the identical plane or substantially identical plane to the flat face of the first convex lens.

[0020]

In the optical system according to the present invention, more preferably the first hole has a rotationally symmetric or substantially rotationally symmetric shape, the rotational symmetry axis of the

first hole and the optical axis of the first convex lens coincide or substantially coincide, and the concave curved face of the first base material forms an annular inclined face.

[0021]

In the optical system according to the present invention, preferably, in the second base material, a second hole communicating with the fourth face is formed from the deep side of the concave curved face closely contacting the convex curved face of the second convex lens, and part of the convex curved face of the second convex lens is exposed in the second hole of the second base material.

[0022]

In the optical system according to the present invention, preferably the second convex lens has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face facing this flat face, and the optical axis of the second convex lens or the extension thereof passes through the second hole.

[0023]

In the optical system according to the present invention, more preferably the fourth face of the second base material is flat or substantially flat and parallel

or substantially parallel to the flat face of the second convex curved face, and the area around the concave curved face in the third face of the second base material is flat or substantially flat and parallel or substantially parallel to the flat face of the second convex lens.

[0024]

In the optical system according to the present invention, more preferably the fourth face of the second base material is flat or substantially flat and parallel or substantially parallel to the flat face of the second convex curved face, and the area around the concave curved face in the third face of the second base material is flat or substantially flat and located in the identical plane or substantially identical plane to the flat face of the second convex lens.

[0025]

In the optical system according to the present invention, more preferably the second hole has a rotationally symmetric or substantially rotationally symmetric shape, the rotational symmetry axis of the second hole and the optical axis of the second convex lens coincide or substantially coincide, and the concave curved face of the second base material forms an annular inclined face.

[0026]

In the optical system according to the present invention, for example, the material of the first and/or second convex lens can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0027]

In the optical system according to the present invention, preferably the first convex lens is larger than the second convex lens, the first face of the first base material and the fourth face of the second base material are bonded, and a solid immersion lens is comprised by the first and second optical devices.

The optical system according to the present invention can be used in for example a slider of an optical head attached to a swing arm. The material of the second base material in this case is preferably made aluminum oxide or silicon oxide.

[0028]

A first method of production of an optical device according to the present invention is a method for production of an optical device comprising a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising a step of using a

metallic mold formed with a projection projecting out into a cavity to mold a base material formed with a concavity reproducing the shape of the projection, a step of filling an optical material in the concavity of the molded base material, a step of flattening the surface of the optical material filled in the concavity to form the convex lens, and a step of forming a hole so that part of the convex curved face closely contacting the concavity in the convex lens is exposed in the base material.

[0029]

In the first method of production of an optical device according to the present invention, preferably the method further has a step of polishing the base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[0030]

In the first method of production of an optical device according to the present invention, more preferably the step of forming the hole in the base material has a step of forming a resist film having a window on the flat face of the base material formed in the step of polishing the base material, a step of forming a hole corresponding to the window in the base material by etching, and a step of removing the resist

film from the base material.

In the first method of production of an optical device according to the present invention, for example, it is also possible to impart a circular or substantially circular shape to the window.

[0031]

In the first method of production of an optical device according to the present invention, more preferably the step of filling the optical material has a step of forming a coating film covering the surface of the concavity of the molded base material and a step of filling an optical material in the concavity with the coating film formed thereon, the step of forming the hole in the base material has a step of forming a resist film having a window on the flat face of the base material formed in the step of polishing the base material, a step of forming a hole reaching the coating film from the window in the base material by etching, a step of removing the resist film from the base material formed with the hole, and a step of removing a part of the coating film exposed in the hole.

In the first method of production of an optical device according to the present invention, it is also possible to impart a circular or substantially circular shape to the window.

[0032]

In the first method of production of an optical device according to the present invention, preferably the projection has a rotationally symmetric or substantially rotationally symmetric shape, and in the step of forming the convex lens, the surface of the optical material is polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity with the shape of the projection transferred thereto is formed.

In the first method of production of an optical device according to the present invention, more preferably the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or substantially arc.

[0033]

In the first method of production of an optical device according to the present invention, for example, the optical material can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0034]

A second method of production of an optical device according to the present invention is a method for

production of an optical device comprising a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising a step of forming a first resist film having a first window in the flat face of the base material, a step of forming a concavity corresponding to the first window in the base material by etching, a step of removing the first resist film from the base material formed with the concavity, a step of filling an optical material in the concavity of the base material from which the first resist film is removed, a step of flattening the surface of the optical material filled in the concavity to form the convex lens, and a step of forming a hole whereby part of the convex curved face closely contacting the concavity in the convex lens is exposed in the base material.

[0035]

The second method of production of an optical device according to the present invention preferably further has a step of polishing the base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[0036]

In the second method of production of an optical device according to the present invention, more preferably, the step of forming the hole in the base

material has a step of forming a second resist film having a second window in the flat face of the base material formed in the step of polishing the base material, a step of forming a hole corresponding to the second window in the base material by etching, and a step of removing the second resist film from the base material formed with the hole.

In the second method of production of an optical device according to the present invention, for example, it is also possible to impart a circular or substantially circular shape to the second window.

[0037]

In the second method of production of an optical device according to the present invention, more preferably, the step of filling the optical material has a step of forming a coating film covering the surface of the concavity of the base material from which the first resist film has been removed and a step of filling an optical material in the concavity formed with the coating film and the step of forming the hole in the base material has a step of forming a second resist film having a second window in the flat face of the base material formed in the step of polishing the base material, a step of forming a hole reaching the coating film from the second window in the base material by

etching, a step of removing the second resist film from the base material formed with the hole, and a step of removing a part exposed in the hole in the coating film.

In the second method of production of an optical device according to the present invention, for example, it is also possible to impart a circular or substantially circular shape to the second window.

[0038]

In the second method of production of an optical device according to the present invention, preferably the first window is circular or substantially circular, the concavity has a rotationally symmetric or substantially rotationally symmetric shape, and in the step of forming the convex lens, the surface of the optical material is polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity is formed.

In the second method of production of an optical device according to the present invention, more preferably, the shape of the surface of the concavity when the concavity is cut along its symmetry axis is an arc or substantially arc.

[0039]

In the second method of production of an optical device according to the present invention, for example,

the optical material can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0040]

A third method of production of an optical device according to the present invention is a method for production of an optical device comprising a convex lens and a base material closely contacting the convex curved face of this convex lens, comprising a step of forming on a second base material provided with a projection and having a flat area around the projection a first base material made of a layer burying the projection, a step of flattening the surface of the first base material to form a flat face and bonding the related flat face to a third base material, a step of removing the second base material from the first base material bonded to the third base material to expose the concavity with the shape of the projection transferred thereto in the first base material, a step of filling an optical material in the exposed concavity of the first base material, a step of flattening the surface of the optical material filled in the concavity to form the convex lens, and a step of forming holes whereby part of the convex curved face closely contacting the concavity in the convex lens is

exposed in the first and third base materials.

[0041]

The third method of production of an optical device according to the present invention preferably further has a step of polishing the third base material so that a flat face parallel or substantially parallel with respect to the surface of the flattened optical material is formed.

[0042]

In the third method of production of an optical device according to the present invention, more preferably, the step of forming the holes in the first and third base materials has a step of forming a resist film having a window in the flat face of the third base material formed in the step of polishing the third base material, a step of forming holes corresponding to the windows in the first and third base materials by etching, and a step of removing the resist films from the first and third base materials formed with the holes.

In the third method of production of an optical device according to the present invention, for example, it is also possible to impart a circular or substantially circular shape to the windows.

[0043]

In the third method of production of an optical

device according to the present invention, more preferably, the step of filling the optical material has a step of forming a coating film covering the surface of the exposed concavity of the first base material and a step of filling an optical material in the concavity formed with the coating film, and the step of forming the hole in the base material has a step of forming a resist film having a window in the flat face of the third base material formed in the step of polishing the third base material, a step of forming holes reaching the coating film from the window in the first and third base materials by etching, a step of removing the resist films from the first and third base materials formed with the holes, and a step of removing the part exposed in the hole in the coating film.

In the third method of production of an optical device according to the present invention, for example, it is also possible to impart a circular or substantially circular shape to the windows.

[0044]

In the third method of production of an optical device according to the present invention, preferably the projection has a rotationally symmetric or substantially rotationally symmetric shape, and in the step of forming the convex lens, the surface of the optical material is

polished so that a flat face vertical or substantially vertical with respect to the symmetry axis of the concavity with the shape of the projection transferred thereto is formed.

In the third method of production of an optical device according to the present invention, more preferably, the shape of the surface of the projection when the projection is cut along its symmetry axis is an arc or substantially arc.

[0045]

In the third method of production of an optical device according to the present invention, preferably the first and third base materials are identical materials.

[0046]

In the third method of production of an optical device according to the present invention, for example, the optical material can be made titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride.

[0047]

In the first method of production of an optical device according to the present invention, the metallic mold has a projection projecting out into the cavity. By molding the base material by this metallic mold, a

concavity with the shape of the projection transferred thereto can be formed in the base material.

By reducing the size of the projection of the metallic mold, the sizes of the concavity of the base material and the convex lens can be reduced, so it is possible to create a small sized optical device.

By forming a hole for exposing part of the convex curved face of the convex lens in the base material in part of the convex curved face, light can be refracted by utilizing a difference of a refractive index between air and the convex lens.

Also, by using a material having a large refractive index as the optical material, for example titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0048]

In the second method of production of an optical device according to the present invention, by forming the resist film having a window on the flat face of the base material, a concavity corresponding to the window can be formed by etching.

By reducing the size of the window, the sizes of the

concavity and the convex lens of the base material can be reduced, so it is possible to create a small sized optical device.

By forming a hole for exposing part of the convex curved face of the convex lens in the base material in part of the convex curved face, light can be refracted by utilizing the difference of the refractive index between air and the convex lens.

Also, by using a material having a large refractive index as the optical material, for example titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0049]

In the third method of production of an optical device according to the present invention, the second base material is provided with the projection, and the area around the related projection is flat.

By forming a first base material made of a layer burying the projection on this second base material, a concavity with the shape of the projection transferred thereto can be formed in the first base material.

By flattening the surface of the first base material

to form the flat face, bonding the related flat face to the third base material, and removing the second base material from the first base material bonded to the third base material, the concavity with the shape of the projection transferred thereto in the first base material can be exposed.

By reducing the size of the projection, the sizes of the concavity and the convex lens of the base material can be reduced, so it is possible to create a small sized optical device.

By forming the holes for exposing part of the convex curved face of the convex lens in the first and third base materials in part of the convex curved face, light can be refracted by utilizing the difference of the refractive index between air and the convex lens.

Also, by using a material having a large refractive index as the optical material, for example titanium oxide, tantalum oxide, niobium oxide, gallium phosphate, gallium nitride, a compound of titanium, niobium, and oxygen, a compound of titanium, tantalum, and oxygen, or silicon nitride, it is possible to create an optical device having a large numerical aperture.

[0050]

[Embodiments of the Invention]

Below, embodiments of the present invention will be

explained by referring to the attached drawings.

[0051]

Optical Device

Figure 1 is a schematic view of the configuration of an embodiment of an optical device according to the present invention.

This optical device 100 is shaped as a parallelopiped or a substantial parallelopiped provided with a hole 103. The optical device 100 has a base material (substrate) 101 and a convex lens 102.

[0052]

The optical device 100 can converge (condense) or scatter a beam emitted from the flat face of the convex lens 102 by the convex lens 102 or can change it to a parallel beam when light enters the convex lens 102 through the hole 103 from an upper face 100U of the base material 101. In the base material 101, a first face, that is, a lower face 100B, and a second face, that is, the upper face 100U, face each other.

[0053]

In the base material 101, a concave curved face 101C closely contacting a convex curved face 102C of the convex lens 102 is formed in the lower face 100B. At the same time, the hole 103 communicating with the upper face 100U is formed from a deep side of the concave curved

face 101C.

Part (concretely a center portion) of the convex curved face of the convex lens 102 is exposed at the hole 103 of the base material 101. The concave curved face 101C forms an annular inclined face.

[0054]

The convex lens 102 has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face 102C facing this flat face. The optical axis of the convex lens 102 or the extension thereof passes through the hole 103. The shape of the convex curved face 102C when the convex lens 102 is cut along its symmetry axis is preferably made an arc or substantially arc.

The hole 103 has a rotationally symmetric or substantially rotationally symmetric shape. The symmetry axis of the hole 103 and the optical axis of the convex lens 102 coincide or substantially coincide.

[0055]

The flat face of the convex lens 102 is parallel or substantially parallel to the upper face 100U of the optical device 100 (or the upper face of the base material 101). Also, the flat portion (or flat face) at the area around the concave curved face 101C in the lower face 100B of the base material 101 and the flat face of

the convex lens 102 are parallel or substantially parallel and are located in an identical plane in Fig. 1.

[0056]

It is also possible to make the material of the base material 101 for example quartz and make the material of the convex lens 102 for example silicon nitride. Also, it is also possible to make the material of the base material 101 for example silicon nitride and make the material of the convex lens 102 for example quartz.

By making the material of the convex lens 102 an optical material having a large refractive index, the numerical aperture of the convex lens 102 can be enlarged.

Also, in the optical device 100, since the hole 103 is provided, part of the convex curved face 102C of the convex lens 102 contacts the air, so the difference of the refractive indexes at the curved face 102C can be made larger. For this reason, the numerical aperture of the convex lens 102 can be enlarged, and aberration can be kept small in comparison with a case where the hole 103 is not provided, that is, the whole area of the convex curved face 102C of the convex lens 102 is covered by the base material of the optical material.

[0057]

<u>First Embodiment of Method of Production of Optical</u>

Device

Figures 2 to 4 are schematic explanatory views of a first embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

[0058]

Figure 2(A) shows a metallic mold 3. This metallic mold 3 is formed with a passageway 4 for passing a liquid-like or fluid-like optical material 6L and a cavity 3C. Also, a bottom portion of the metallic mold 3 is formed with a projection 5 projecting out into the cavity 3C, and the area around the projection 5 is flat. The projection 5 has an identical shape to the convex lens 102 of the optical device 100 of Fig. 1 and has a rotationally symmetric or substantially rotationally symmetric shape.

[0059]

In Fig. 2(B), the material 6L is injected into the cavity 3C from the passageway 4 of the metallic mold 3 to fill the material 6L in the cavity 3C. The material 6L injected is made for example molten quartz, glass, plastic, or a synthetic resin. The explanation will be given below with reference to a case where the material

6L is an optical material.

[0060]

In Fig. 2(C), the liquid-like material 6L is hardened to a solid-state optical material 6M, and a base material 6 made of the optical material 6M is taken out from the metallic mold 3. The shape of the projection 5 is transferred to the lower portion of the base material 6 taken out from the metallic mold 3 to form a concavity 6B. The area around the concavity 6B of the base material 6 is flat.

[0061]

In Fig. 3(D), an optical material 7M is filled in the concavity 6B of the bottom portion of the base material 6. The optical material 7M has a different refractive index from the optical material 6M, preferably has a larger refractive index than the optical material 6M, and is made gallium nitride as an example.

For example, by forming a layer 7 of the optical material 7M on the bottom portion of the base material 6 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity 6B of the base material 6. In this case, a concavity 7B corresponding to the concavity 6B is formed in the layer 7.

[0062]

In Fig. 3(E), the bottom face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7 disappears. Preferably, the bottom face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 6B of the base material 6 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) on the area around the concavity 6B of the base material 6 and the bottom face of the layer 7 become parallel or substantially parallel. Note that it is also possible to polish the layer 7 so that the flat portion on the area around the concavity 6B of the base material 6 is exposed.

In this way, a convex lens made of the optical material 7M is formed. The convex curved face of this convex lens closely contacts (the surface of) the concavity 6B of the base material 6.

[0063]

In Fig. 4(F), the upper face of the base material 6 is polished so as to become parallel or substantially parallel with respect to the flat face of the flattened layer 7. Also, by this polishing, the base material 6 can be reduced to an intended thickness.

[0064]

In Fig. 4(G), a resist film 50 having a window 50H

is formed on the upper face, that is, flat face, of the base material 6. The shape of the window 50H is preferably made circular or substantially circular. The concavity 6B of the base material 6 is located at the lower side of the window 50H. As illustrated, the window 50H has a hole and/or opening portion of the resist film 50.

[0065]

In Fig. 4(H), a hole 51 reaching a convex curved face 7C of the convex lens from the window 50H is formed by etching. Part of the convex curved face 7C (preferably the center portion of the curved face 7C) of the convex lens is exposed in the hole 51. By the hole 51, the surface of the concavity 6B of the base material 6 is partially removed and becomes a concave curved face (specifically an annular inclined face) 6C closely contacting the convex curved face 7C.

For example, the hole 51 is formed by dry etching part of the base material 6 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0066]

In Fig. 4(I), the resist film 50 is removed from the base material 6 formed with the hole 51. In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure

to the optical device 100 of Fig. 1.

Note that the base material 6, hole 51, convex curve 7C, concave curve 6C, and upper face 6U of Fig. 4(H) and the base material 101, hole 103, convex curve 102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0067]

The bottom portion of the metallic mold 3 of Figs. 2(A) and 2(B) has the projection 5 projecting out into the cavity 3C, so the processing precision can be improved in comparison with a case of forming a concavity having a sunken shape in the cavity 3C and preparing a convex lens by simple molding. In this way, by using the metallic mold 3, it is possible to prepare a small sized convex lens having a higher processing precision than a convex lens obtained by simple molding.

[0068]

Note that it is also possible to mold the lens by using an upper mold and a lower mold in place of the metallic mold shown in Figs. 2(A) and 2(B). The projection is formed at the bottom portion of the lower mold, and the area around the this projection is flat. This projection is identical to the projection 5 of the metallic mold 3.

First, by injecting the material (for example the

glass material) of the base material 6 into the cavity between the upper mold and the lower mold and simultaneously heating the glass material, lower mold, and upper mold to a predetermined temperature, the glass material is softened. Then, the softened glass material is pressed by the upper mold.

Next, the glass material, lower mold, and upper mold are cooled to harden the glass material and the base material 6 is taken out from the metallic molds. The shape of the projection at the bottom portion of the lower mold is transferred to the bottom portion of this base material 6 taken out from the metallic molds to form the concavity 6B.

In this way, it is also possible to obtain the base material 6 shown in Fig. 2(C).

[0069]

Second Embodiment of Method of Production of Optical Device

Figures 5 to 7 are schematic explanatory views of a second embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or substantially identical configuration to the optical device 100 of Fig. 1.

[0070]

In Fig. 5(A), a resist 9 is formed on the flat face of a silicon substrate 8 - an example of the base material. The size of the bottom face of the resist 9 is made identical or substantially identical to the size of the bottom face of the convex lens 102 in Fig. 1.

[0071]

In Fig. 5(B), a projection 8U is formed at the surface of the silicon substrate 8 by etching using the resist 9 as a mask. The shape of the projection 8U is identical to the shape of the convex lens 102 and is rotationally symmetric or substantially rotationally symmetric. As the etching, use is made of for example ion milling or RIE.

[0072]

In Fig. 5(C), a material 10M is laminated on the surface of the silicon substrate 8 formed with the projection 8U so that the projection 8U is buried to thereby form a base material made of a layer 10 of the material 10M. It is also possible to form the layer 10 by for example sputtering, vapor deposition, or ion implantation. Below, an explanation will be made by referring to a case where the material 10M is an optical material.

When the layer 10 is formed on the silicon substrate 8, a projection 10U corresponding to the projection 8U is

formed on the upper face of the layer 10.

[0073]

In Fig. 5(D), the upper face of the layer 10 is flattened. For example, it is polished so that the projection 10U of the upper face of the layer 10 disappears. Preferably, the upper face of the layer 10 is polished so that a flat face vertical with respect to the symmetry axis of the projection 8U of the silicon substrate 8 is formed. Alternatively, the layer 10 is polished so that the flat portion (or flat face) on the area around the projection 8U of the silicon substrate 8 and the upper face of the layer 10 become parallel or substantially parallel.

[0074]

In Fig. 5(E), the flat face of a base material 11 made of a material 11M is bonded to a flattened upper face 10S of the layer 10. As the bonding method, for example, it is possible to bond by a transparent adhesive or to bond by anodic bonding. The material 11M is preferably made the same material as the material 10M. Below, an explanation will be made referring to a case where the material 11M is an optical material.

[0075]

In Fig. 6(F), the silicon substrate 8 bonded to the lower face of the layer 10 of Fig. 5(E) is removed to

expose the lower face of the layer 10. It is also possible to dissolve the silicon substrate 8 by for example an aqueous solution of potassium hydroxide to remove it.

The shape of the projection 8U of the silicon substrate 8 is transferred to the lower face of the layer 10 to form a concavity 10B corresponding to the projection 8U.

[0076]

In Fig. 6(G), the optical material 7M is filled in the concavity 10B of the lower face of the layer 10. The optical material 7M has a different refractive index from the optical material 10M, preferably has a larger refractive index than the optical material 10M. Silicon nitride is used as an example.

For example, by forming the layer 7 of the optical material 7M on the lower face of the layer 10 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity 10B of the layer 10. In this case, a concavity 7B corresponding to the concavity 10B is formed in the layer 7.

[0077]

In Fig. 6(H), the lower face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7

disappears. Preferably, the bottom face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 10B of the layer 10 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) on the area around the concavity 10B of the layer 10 and the bottom face of the layer 7 become parallel or substantially parallel. Note that it is also possible to polish the layer 7 so that the flat portion of the area around the concavity 10B of the base material 10 is exposed.

In this way, a convex lens made of the optical material 7M is formed. The convex curved face of this convex lens closely contacts the (surface of) the concavity 10B of the base material 10.

[0078]

In Fig. 7(I), the upper face of the base material 11 is polished so as to become parallel or substantially parallel with respect to the polished face of the layer 7. Also, by this polishing, the base material 11 can be reduced to the intended thickness.

[0079]

In Fig. 7(J), a resist film 52 having a window 52H is formed on the upper face, that is, the flat face, of the base material 11. The shape of the window 52H is preferably made circular or substantially circular. The

concavity 10B of the base material 10 is located at the lower side of the window 52H. As illustrated, the window 52H comprises the hole and/or opening portion of the resist film 52.

[0080]

In Fig. 7(K), a hole 53 reaching the convex curved face 7C of the convex lens from the window 52H is formed by etching, and part of the convex curved face 7C (preferably the center portion of the curved face 7C) of the convex lens is exposed in the hole 53. By the hole 53, the surface of the concavity 10B of the base material 10 is partially removed and becomes a concave curved face (specifically an annular inclined face) 10C closely contacting the convex curved face 7C.

For example, the hole 53 is formed by dry etching part of the base materials 10 and 11 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0081]

In Fig. 7(L), the resist film 52 is removed from the base material 11 formed with the hole 53. In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

Note that the base materials 10 and 11, hole 53,

convex curve 7C, concave curve 10C, and upper face 11U of Fig. 7(L) and the base material 101, hole 103, convex curve 102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0082]

Third Embodiment of Method of Production of Optical Device

Figures 8 to 10 are schematic explanatory views of a third embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or substantially identical configuration to the optical device 100 of Fig. 1.

[0083]

In Fig. 8(A), a resist 19 is formed on the flat face of a silicon substrate 18 - an example of the base material. The size of the bottom face of the resist 19 is made identical or substantially identical to the size of the bottom face of the convex lens 102 in Fig. 1.

[0084]

In Fig. 8(B), a material 20M is laminated on the surface of the silicon substrate 18 formed with the resist 19 so that the resist 19 is buried to thereby form a base material made of a layer 20 of the material 20M.

It is also possible to form the layer 20 of the material 20M by using for example sputtering, vapor deposition, or ion implantation. It is also possible to use for example aluminum oxide as the material 20M. Below, an explanation will be made with reference to a case where the material 20M is an optical material.

When the layer 20 is formed on the silicon substrate 18, a projection 20U in accordance with the resist 19 is formed on the surface of the layer 20.

[0085]

In Fig. 8(C), the upper face of the layer 20 is flattened. For example, it is polished so that the projection 20U of the upper face of the layer 20 disappears. Preferably, the upper face of the layer 20 is polished so that a flat face vertical with respect to the symmetry axis of the resist 19 on the silicon substrate 18 is formed. Alternatively, the layer 20 is polished so that the flat portion (or flat face) on the area around the resist 19 on the silicon substrate 18 and the upper face of the layer 20 become parallel or substantially parallel.

[0086]

In Fig. 8(D), the flat face of a base material 21 made of a material 21M is bonded to an upper face 20S of the layer 20. As the bonding method, for example, it is

also possible to bond by a transparent adhesive or to bond by anodic bonding. The material 21M is preferably made the same material as the material 20M. Below, an explanation will be made with reference to a case where the material 21M is an optical material.

[0087]

In Fig. 9(E), the silicon substrate 18 and the resist 19 bonded to the lower face of the layer 20 of Fig. 8(D) are removed to expose the lower face of the layer 20. It is also possible to dissolve the silicon substrate 18 by for example an aqueous solution of potassium hydroxide to remove it. It is also possible to dissolve and remove the resist 19 by for example a resist use peeling liquid or an organic solvent (for example acetone) for a resist.

The shape of the resist 19 is transferred to the lower face of the layer 20 to form a concavity 20B corresponding to the shape of the resist 19.

[0088]

In Fig. 9(F), the optical material 7M is filled in the concavity 20B of the lower face of the layer 20. The optical material 7M has a different refractive index from the optical material 20M, preferably has a larger refractive index than the optical material 20M. Gallium nitride is used as an example.

For example, by forming the layer 7 of the optical material 7M on the lower face of the layer 20 by sputtering, vapor deposition, or ion implantation, the optical material 7M is filled in the concavity 20B of the layer 20. In this case, a concavity 7B corresponding to the concavity 20B is formed in the layer 7.

[0089]

In Fig. 9(G), the lower face of the layer 7 is flattened. For example, it is polished so that the concavity 7B of the bottom face of the layer 7 disappears. Preferably, the bottom face of the layer 7 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 20B of the layer 20 is formed. Alternatively, the layer 7 is polished so that the flat portion (or flat face) on the area around the concavity 20B of the layer 20 and the bottom face of the layer 7 become parallel or substantially parallel. Note that it is also possible to polish the layer 7 so that the flat portion on the area around the concavity 20B of the base material 20 is exposed.

In this way, a convex lens made of the optical material 7M is formed. The convex curved face of this convex lens closely contacts (the surface of) the concavity 20B of the base material 20.

[0090]

In Fig. 10(H), the upper face of the base material 21 is polished so as to become parallel or substantially parallel with respect to the polished face of the layer 7. Also, by this polishing, the base material 21 can be reduced to the intended thickness.

[0091]

In Fig. 10(I), a resist film 54 having a window 54H is formed on the upper face, that is, flat face, of the base material 21. The shape of the window 54H is preferably made circular or substantially circular. The concavity 20B of the base material 20 is located at the lower side of the window 54H. As illustrated, the window 54H comprises the hole and/or opening portion of the resist film 54.

[0092]

In Fig. 10(J), a hole 55 reaching the convex curved face 7C of the convex lens from the window 54H is formed by etching. Part of the convex curved face 7C (preferably the center portion of the curved face 7C) of the convex lens is exposed in the hole 55. By the hole 55, the surface of the concavity 20B of the base material 20 is partially removed and becomes the concave curved face (concretely the annular inclined face) 20C closely contacting the convex curved face 7C.

For example, the hole 55 is formed by dry etching

part of the base materials 20 and 21 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0093]

In Fig. 10(K), the resist film 54 is removed form the base material 21 formed with the hole 55. In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

Note that the base materials 20 and 21, hole 55, convex curve 7C, concave curve 20C, and upper face 21U of Fig. 10(K) and the base material 101, hole 103, convex curve 102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0094]

<u>Fourth Embodiment of Method of Production of Optical Device</u>

Figures 11 to 13 are schematic explanatory views of a fourth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical configuration or substantially identical configuration to the optical device 100 of Fig. 1.

[0095]

In Fig. 11(A), a resist film 29 is formed on the flat face of a base material 31 made of a material 31M. The material 31M is made for example quartz. Below, the explanation will be made with reference to a case where the material 31M is an optical material.

A circular or substantially circular window 29H is formed in the resist film 29 on the base material 31. As illustrated, the window 29H comprises the hole and/or opening portion of the resist film 29.

[0096]

In Fig. 11(B), the base material 31 with the resist film 29 formed thereon is immersed in an etching solution 32 for a predetermined time. The etching solution 32 is comprised of for example a solution of fluoric acid corroding quartz.

By immersing the base material 31 in the etching solution 32 for a predetermined time, the base material 31 is gradually corroded from the window 29H of the resist film 29, and a concavity 31U is formed at the lower side of the window 29H. The size of this concavity 31U is made identical or substantially identical to the size of the convex lens 102 in Fig. 1.

[0097]

In Fig. 12(C), the base material 31 is taken out from the etching solution 32, and the resist film 29 is

removed. It is also possible to dissolve and remove the resist film 29 by a resist use peeling liquid or organic solvent (for example acetone) etc.

[0098]

In Fig. 12(D), an optical material 27M is filled in the concavity 31U of the upper face of the base material 31. The optical material 27M has a different refractive index from the optical material 31M, preferably has a larger refractive index than the optical material 31M. Gallium nitride is used as an example.

For example, by forming a layer 27 of the optical material 27M on the upper face of the base material 31 by sputtering, vapor deposition, or ion implantation, the optical material 27M is filled in the concavity 31U of the base material 31. In this case, a concavity 27U corresponding to the concavity 31U is formed in the layer 27.

[0099]

In Fig. 12(E), the upper face of the layer 27 is flattened. For example, it is polished so that the concavity 27U of the upper face of the layer 27 disappears. Preferably, the upper face of the layer 27 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 31U of the base material 31 is formed. Alternatively, the layer 27 is polished so

that the flat portion (or flat face) on the area around the concavity 31U of the base material 31 and the upper face of the layer 27 become parallel or substantially parallel. Note that it is also possible to polish the layer 27 so that the flat portion on the area around the concavity 31U of the base material 31 is exposed.

In this way, a convex lens made of the optical material 27M is formed. The convex curved face of this convex lens closely contacts (the surface of) the concavity 31U of the base material 31.

[0100]

In Fig. 13(F), the surface of the base material 31 is polished so as to become parallel or substantially parallel with respect to the polished face of the layer 27. Also, by this polishing, the base material 31 can be reduced to the intended thickness.

[0101]

In Fig. 13(G), a resist film 56 having a window 56H is formed on the polished flat face of the base material 31. The shape of the window 56H is preferably made circular or substantially circular. The concavity 31U of the base material 31 is located at the lower side of the window 56H. As illustrated, the window 56H comprises the hole and/or opening portion of the resist film 56.

[0102]

In Fig. 13(H), a hole 57 reaching a convex curved face 27C of the convex lens from the window 56H is formed by etching, and part of the convex curved face 27C (preferably the center portion of the curved face 27C) of the convex lens is exposed in the hole 57. By the hole 57, the surface of the concavity 31U of the base material 31 is partially removed and becomes the concave curved face (concretely the annular inclined face) 31C closely contacting the convex curved face 27C.

For example, the hole 57 is formed by dry etching part of the base material 31 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0103]

In Fig. 13(I), the resist film 56 is removed from the base material 31 formed with the hole 57. In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

Note that the base material 31, hole 57, convex curve 27C, concave curve 31C, and flat face 31B of Fig. 13(I) and the base material 101, hole 103, convex curve 102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0104]

<u>Fifth Embodiment of Method of Production of Optical</u>

Device

Figure 14 and Fig. 15 are schematic explanatory views of a fifth embodiment of the method of production of an optical device. By this method of production, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

[0105]

In Fig. 14(A), a base material 41 having a concavity 41U is shown. The concavity 41U has a rotationally symmetric or substantially rotationally symmetric shape. The circumference (or periphery) of the concavity 41U in the base material 41 is flat. The base material 41 is made of a material 41M. Below, an explanation will be made with reference to a case where the material 41M is an optical material.

The size of the concavity 41U is identical or substantially identical to the size of the convex lens 102 in Fig. 1.

As this base material 41, use is made of for example the base material 6 in Fig. 2(C), the base material 11 with the layer 10 bonded thereto in Fig. 6(F), the base material 21 with the layer 20 bonded thereto in Fig. 9(E), or the base material 31 in Fig. 12(C).

[0106]

In Fig. 14(B), an optical material 37M having a different refractive index from the optical material 41M is filled in the concavity 41U of the upper face of the base material 41.

As an example, by using gelated quartz as the optical material 37M and coating the same on the upper face of the base material 41, a layer 37 of the optical material 37M is formed, and the optical material 37M is filled in the concavity 41U of the base material 41.

Then, the base material 41 with the optical material 37M filled in its concavity 41U is heated to harden the optical material 37M.

[0107]

In Fig. 14(C), the upper face of the hardened layer 37 is flattened. For example, it is polished so that surface roughness or undulation of the upper face of the optical material 37 disappears. Preferably, the upper face of the layer 37 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 41U of the base material 41 is formed. Alternatively, the layer 37 is polished so that the flat portion (or flat face) on the area around the concavity 41U of the base material 41 and the upper face of the layer 37 become parallel or substantially parallel. Note that it is also possible to polish the layer 37 so that

the flat portion on the area around the concavity 41U of the base material 41 is exposed.

In this way, a convex lens made of the optical material 37M is formed. The convex curved face of this convex lens closely contacts (the surface of) the concavity 41U of the base material 41.

[0108]

In Fig. 15(D), the surface of the base material 41 is polished so as to become parallel or substantially parallel with respect to the polished face of the layer 37. Also, by this polishing, the base material 41 can be reduced to the intended thickness.

[0109]

In Fig. 15(E), a resist film 58 having a window 58H is formed on the polished flat face of the base material 41. The shape of the window 58H is preferably made circular or substantially circular. The concavity 41U of the base material 41 is located at the lower side of the window 58H. As illustrated, the window 58H comprises the hole and/or opening portion of the resist film 58.

[0110]

In Fig. 15(F), a hole 59 reaching a convex curved face 37C of the convex lens from the window 58H is formed by etching, and part of the convex curved face 37C (preferably the center portion of the curved face 37C) of

the convex lens is exposed in the hole 59. By the hole 59, the surface of the concavity 41U of the base material 41 is partially removed and becomes the concave curved face (concretely the annular inclined face) 41C closely contacting the convex curved face 37C.

For example, the hole 59 is formed by dry etching part of the base material 41 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0111]

In Fig. 15(G), the resist film 58 is removed from the base material 41 formed with the hole 59. In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

Note that the base material 41, hole 59, convex curve 37C, concave curve 41C, and flat face 41B of Fig. 15(G) and the base material 101, hole 103, convex curve 102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0112]

<u>Sixth Embodiment of Method of Production of Optical Device</u>

Figure 16 and Fig. 17 are schematic explanatory views of a sixth embodiment of the method of production of an optical device. By this method of production, it is

possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

[0113]

In Fig. 16A), a base material 86 having a concavity 86B is shown. The concavity 86B has a rotationally symmetric or substantially rotationally symmetric shape. The circumference (or periphery) of the concavity 86B in the base material 86 is flat. The base material 86 is made of a material 86M. Below, an explanation will be made with reference to a case where the material 86M is an optical material.

The size of the concavity 86B is identical or substantially identical to the size of the convex lens 102 in Fig. 1.

As this base material 86, use is made of for example the base material 6 in Fig. 2(C), the base material 11 with the layer 10 bonded thereto in Fig. 6(F), the base material 21 with the layer 20 bonded thereto in Fig. 9(E), or the base material 31 in Fig. 12(C).

[0114]

In Fig. 16(B), a coating film 85 covering the surface of the concavity 86B of the base material 86 is formed. The coating film 85 is made of a metal film, for example, aluminum or nickel.

Note that it is also possible to form the coating film 85 so as to cover the concavity 86B of the base material 86 and the flat portion (or flat face) at the area around it.

[0115]

In Fig. 16(C), an optical material 87M is filled in the concavity 86B of the base material 86 formed with the coating film 85. The optical material 87M has a different refractive index from the optical material 86, preferably has a larger refractive index than the optical material 86. Silicon nitride is used as an example.

For example, by forming a layer 87 of the optical material 87M on the bottom face of the base material 86 by sputtering, vapor deposition, or ion implantation, the optical material 87M is filled in the concavity 86B of the base material 86.

[0116]

Then, the surface of the layer 87 is flattened. For example, it is polished so that the concavity of the bottom face of the layer 87 disappears. Preferably, the bottom face of the layer 87 is polished so that a flat face vertical with respect to the symmetry axis of the concavity 86B of the base material 86 is formed. Alternatively, the layer 87 is polished so that the flat portion (or flat face) on the area around the concavity

86B of the base material 86 and the bottom face of the layer 87 become parallel or substantially parallel. Note that it is also possible to polish the layer 87 so that the flat portion on the area around the concavity 86B of the base material 86 is exposed.

In this way, a convex lens made of the optical material 87M is formed. The convex curved face of this convex lens closely contacts (the surface of) the concavity 86B of the base material 86 via the coating film 85.

Next, the upper face of the base material 86 is polished so as to become parallel or substantially parallel with respect to the flat face of the flattened layer 87.

[0117]

In Fig. 17(D), a resist film 82 having a window 82H is formed on the flat face of the upper face of the base material 86. The shape of the window 82H is preferably made circular or substantially circular. The concavity 86B of the base material 86 is located at the lower side of the window 82H. As illustrated, the window 82H comprises the hole and/or opening portion of the resist film 82.

[0118]

In Fig. 17(E), a hole 83 reaching the coating film

85 from the window 82H is formed by etching, and part of the coating film 85 (preferably the center portion of the coating film 85) is exposed in the hole 83. By the hole 83, the surface of the concavity 86B of the base material 86 is partially removed and becomes the concave curved face (concretely the annular inclined face) 86C closely contacting the convex curved face of the convex lens via the coating film 85.

For example, the hole 83 is formed by dry etching part of the base material 86 in a reactive ion etching apparatus (RIE apparatus) using CF_4 as the etching gas.

[0119]

In Fig. 17(F), the resist film 82 is removed from the base material 86 formed with the hole 83. Also, the exposed portion exposed in the hole 83 in the coating film 85 is removed to expose a convex curved face 87C of the convex lens. For example, when the coating film 85 is a metal film, it is also possible to dissolve and remove the exposed portion by using an alkali aqueous solution.

In this way, it is possible to obtain an optical device having an identical structure or substantially identical structure to the optical device 100 of Fig. 1.

Note that the base material 86, hole 83, convex curve 87C, concave curve 86C, and upper face 86U of Fig. 17(F) and the base material 101, hole 103, convex curve

102C, concave curve 101C, and upper face 100U of the optical device 100 of Fig. 1 correspond to each other.

[0120]

First Embodiment of Optical System

Figure 18 is a schematic view of the configuration of a first embodiment of an optical system using an optical device according to the present invention.

This optical system 119 has optical devices 100 and 110 and is comprised by stacking the optical devices 100 and 110. Note that the optical device 100 is identical or substantially identical to the optical device 100 of Fig. 1, so the explanation thereof will be appropriately omitted.

[0121]

The optical device 110 is shaped as a parallelopiped or a substantial parallelopiped provided with a hole 113. The optical device 110 has a base material (substrate) 111 and a convex lens 112.

In the base material 111, a first face, that is, a lower face 110B, and a second face, that is, an upper face 110U, face each other.

[0122]

In the base material 111, a concave curved face (concretely an annular inclined face) 111C closely contacting a convex curved face 112C of the convex lens

112 is formed in the lower face 110B of the base material 111. At the same time, a hole 113 communicating with the upper face 110U is formed from the deep side of the concave curved face 111C.

Then, part (concretely the center portion) of the convex curved face of the convex lens 112 is exposed in the hole 113 of the base material 111.

[0123]

The convex lens 112 has a rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face 112C facing this flat face. The optical axis of the convex lens 112 or the extension thereof passes through the hole 113. The shape of the convex curved face 112C when the convex lens 112 is cut along its symmetry axis is preferably made circular or substantially circular.

The hole 113 has the rotationally symmetric or substantially rotationally symmetric shape, and the symmetry axis of the hole 113 and the optical axis of the convex lens 112 coincide or substantially coincide. A radius of the hole 113 is smaller than the radius of the convex lenses 102 and 112.

[0124]

The flat face of th convex lens 112 is parallel or substantially parallel to the upper face 110U of the

optical device 110 (or the upper face of the base material 111). Also, the flat portion on the area around the concave curved face 111C in the lower face 110B of the base material 111 and the flat face of the convex lens 112 are parallel or substantially parallel and located in the identical plane in Fig. 18.

[0125]

It is also possible to make the material of the base material 111 for example quartz and make the material of the convex lens 112 for example silicon nitride. Also, it is also possible to make the material of the base material 111 for example silicon nitride and make the material of the convex lens 112 for example quartz.

[0126]

The base material 111, convex lens 112, upper face 110U, and lower face 110B of the optical device 110 correspond to the base material 101, convex lens 102, upper face 100U, and lower face 100B of the optical device 100.

[0127]

In the optical system 119, the lower face 100B of the optical device 100 and the upper face 110U of the optical device 110 are bonded so that the optical axes of the convex lenses 102 and 112 coincide or substantially coincide.

[0128]

It is also possible to form the optical devices 100 and 110 in a plate-like or substantially plate-like shape. It is possible to stack the optical devices 100 and 110 while positioning them with a high precision.

For example, by adding positioning marks like the marks for mask alignment used when semiconductor integrated circuits are manufactured on the base materials 101 and 111, it is possible to use these marks to stack a plurality of optical devices with a high precision.

[0129]

Also, by making the shapes of the optical devices 100 and 110 parallelopipeds or substantial parallelopipeds or plate-like or substantially plate-like, it is possible to prevent inclination of (the optical axes of) the lenses from occurring when the optical devices are stacked, the optical devices can be stacked while positioning them in the two-dimensional direction (vertical and lateral directions), and it is possible to easily prepare the optical system 119.

[0130]

<u>Second Embodiment of Optical System</u>

Figure 19 is a schematic view of the configuration of a second embodiment of an optical system using optical

devices according to the present invention. Note that the optical device 100 in Fig. 19 is identical or substantially identical to the optical device 100 of Fig. 1, so the explanation thereof will be appropriately omitted.

This optical system 119A has optical devices 100 and 700 and is comprised by stacking the optical devices 100 and 700.

[0131]

The optical device 700 has a base material 701 and a lens 702. The base material 701 is made of an optical material. The base material 701 and the lens 702 have different refractive indexes. As the optical device 700, it is also possible to use for example the base material 6 with the optical material 7M filled in its concavity 6B as shown in Fig. 4(F). The material 6M of the base material 6 in this case is made an optical material.

Similarly, as the optical device 700, it is also possible to use the base material 10 or 11 with the optical material 7M filled in its concavity 10B as shown in Fig. 7(I). The materials 10M and 11M of the base materials 10 and 11 in this case are made optical materials. Note that the same is true for Fig. 10(H), Fig. 13(F), and Fig. 15(D).

[0132]

The base material 701 has a rotationally symmetric or substantially rotationally symmetric concavity 701B in the lower face of the base material 701. The shape of the surface of the concavity 701B when the concavity 701B is cut along its symmetry axis is preferably made an arc or substantially arc.

The concavity 701B is filled with an optical material having a different refractive index from the base material 701. The convex lens 702 is comprised by the concavity 701B filled with the related optical material.

[0133]

The lower face of the convex lens 702 is flat and is parallel or substantially parallel to an upper face 700U of the optical device 700 (or the upper face of the base material 701). Also, the flat portions of the lower face of the convex lens 702 and a lower face 700B of the base material 701 are located in the identical plane.

The convex curved face of the convex lens 702 closely contacts the surface of the concavity 701B of the base material 700.

[0134]

The optical device 700 has the shape of a parallelopiped or substantial parallelopiped and can converge (condense) or scatter a beam emitted from the

flat face of the convex lens 702 or can change the same to a parallel beam when light enters the upper face 700U.

The lower face 100B of the optical device 100 and the upper face 700U of the optical device 700 are bonded so that the optical axes of the lenses 102 and 702 coincide or substantially coincide.

[0135]

It is also possible to form the optical devices 100 and 700 plate-like or substantially plate-like. It is possible to stack the optical devices 100 and 700 while positioning them with a high precision.

Also, by making the shape of the optical devices 100 and 700 a parallelopiped or substantial parallelopiped or plate-like or substantially plate-like, it is possible to prevent inclination of (the optical axes of) the lenses from occurring in the case where the optical devices are stacked and it is possible to easily prepare the optical system 119A.

Also, it is possible to comprise a solid immersion lens (SIL) by providing a convex lens 702 smaller than the convex lens 102 in the optical system 119A, and it is possible to obtain a high numerical aperture.

[0136]

<u>Third Embodiment of Optical System</u>

Figure 20 is a schematic view of the configuration

of a third embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 119B of Fig. 20, identical reference numerals are assigned to identical components as those of the optical system 110 in Fig. 18. Explanations of the identical components will be appropriately omitted.

This optical system 119B has optical devices 110 and 710 and is comprised by stacking the optical devices 110 and 710.

[0137]

The optical device 710 has a base material 711 and a convex lens 712. The base material 711 is made of an optical material, and the base material 711 and the convex lens 712 have different refractive indexes. As the optical device 710, it is also possible to use for example a base material 6 with the optical material 7M filled in its concavity 6B as shown in Fig. 4(F). The material 6M of the base material 6 in this case is made an optical material.

Similarly, as the optical device 710, it is also possible to use the base material 10 or 11 with the optical material 7M filled in its concavity 10B as shown in Fig. 7(I). The materials 10M and 11M of the base materials 10 and 11 in this case are made optical materials. Note that the same is true also for Fig.

10(H), Fig. 13(F), and Fig. 15(D).

[0138]

The base material 711 has a rotationally symmetric or substantially rotationally symmetric concavity 711B in the lower face of the base material 711. The shape of the surface of the concavity 711B when the concavity 711B is cut along its symmetry axis is preferably made an arc or substantially arc.

The concavity 711B is filled with an optical material having a different refractive index from the base material 711. The convex lens 712 is comprised by the concavity 711B filled with the related optical material.

[0139]

The lower face of the convex lens 712 is flat and is parallel or substantially parallel to an upper face 710U of the optical device 710 (or the upper face of the base material 711). Also, the flat portions of the lower face of the convex lens 712 and a lower face 710B of the base material 711 are located in the identical plane.

The convex curved face of the convex lens 712 closely contacts the surface of the concavity 711B of the base material 710.

[0140]

The optical device 710 has the shape of

parallelopiped or substantial parallelopiped and can converge (condense) or scatter a beam emitted from the flat face of the convex lens 712 or can change the same to a parallel beam when light enters the upper face 710U.

The lower face 710B of the optical device 710 and the upper face 110U of the optical device 110 are bonded so that the optical axes of the lenses 112 and 712 coincide or substantially coincide.

[0141]

It is also possible to form the optical devices 110 and 710 plate-like or substantially plate-like. It is possible to stack the optical devices 110 and 710 while positioning them with a high precision.

Also, by making the shapes of the optical devices 110 and 710 parallelopipeds or substantial parallelopipeds or plate-like or substantially plate-like, it is possible to prevent the inclination of (the optical axes of) the lenses from occurring in the case where the optical devices are stacked and it is possible to easily prepare the optical system 119B.

[0142]

Fourth Embodiment of Optical System

Figure 21 is a schematic view of the configuration of a fourth embodiment of an optical system using optical devices according to the present invention. Note that in

an optical system 149 of Fig. 21, identical reference numerals are assigned to identical components as those of the optical system 119 of Fig. 18. Explanations of the identical components will be appropriately omitted.

[0143]

This optical system 149 has optical devices 100, 110, and 120, the optical device 110 is stacked upon the optical device 120, and the optical device 100 is stacked upon the optical device 110.

The optical devices 100, 110, and 120 are bonded so that the optical axes of the convex lenses 102, 112, and 122 of the optical devices 100, 110, and 120 coincide or substantially coincide.

[0144]

The optical system 119 has the optical devices 100 and 110.

The convex lens 102 of the optical device 100 is a collimator lens. The convex lens 102 receives a laser beam from a semiconductor laser 60 through the hole 103, changes the related laser beam to a parallel beam, and supplies the same to the optical device 110.

The convex lens 112 of the optical device 110 receives the parallel beam from the optical device 100 through the hole 113 and condenses the laser beam of the related parallel beam to the convex lens 122.

[0145]

The optical device 120 has a base material 121 and the convex lens 122. The base material 121 is made of an optical material. The base material 121 and the convex lens 122 are different in refractive index.

The base material 121 has a rotationally symmetric or substantially rotationally symmetric concavity 121B in the lower face of the base material 121. The shape of the surface of the concavity 121B when the concavity 121B is cut along its symmetry axis is preferably made an arc or substantially arc.

The concavity 121B is filled with an optical material having a different refractive index from the base material 121. The convex lens 122 is comprised by the concavity 121B filled with the related optical material.

[0146]

The lower face of the convex lens 122 is flat and is parallel or substantially parallel to the upper face of the optical device 120 (or the upper face of the base material 121). Also, the flat faces of the lower face of the convex lens 122 and the lower face of the base material 121 are located in the identical plane.

[0147]

The optical device 120 has the shape of a

parallelopiped or substantial parallelopiped and can condense the beam emitted from the flat face of the convex lens 122 of the optical device 120 to the recording surface of an optical disc 80 when light from the convex lens 112 of the optical system 119 strikes it.

[0148]

The optical system 129 has the optical devices 110 and 120. The combination of the optical devices 110 and 120 comprises a solid immersion lens (SIL). By enlarging the refractive index of the convex lens 122, the numerical aperture NA of the optical system 129 can be made higher.

In the optical devices 100 to 120, the convex lenses 102 to 122 are formed by filling the optical material in the concavities of the base materials, so the range of selection of the material of the convex lenses 102 to 122 can be made larger and an optical material having a large refractive index can be used as the material of the convex lenses.

[0149]

Note that, by rounding the edges of the bottom face of the optical device 120 (face facing the optical disc 80), it is possible to reduce collisions with and/or shock to the surface of the optical disc 80.

[0150]

Fifth Embodiment of Optical System

Figure 22 is a schematic view of the configuration of a fifth embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 149A of Fig. 22, identical reference numerals are assigned to identical components as those of the optical system 119A of Fig. 19. Explanations of the identical components will be appropriately omitted. Also, in the optical system 149A of Fig. 22, the optical device 120 in Fig. 21 is used. An explanation of this optical device 120 will be appropriately omitted.

[0151]

This optical system 149A has optical devices 100, 120, and 700, the optical device 700 is stacked upon the optical device 120, and the optical device 100 is stacked upon the optical device 700.

The optical devices 100, 120, and 700 are bonded so that the optical axes of the convex lenses 102, 122, and 702 of the optical devices 100, 120, and 700 coincide or substantially coincide.

[0152]

The optical system 119A has the optical devices 100 and 700.

The convex lens 102 of the optical device 100 is a collimator lens. The convex lens 102 receives the laser

beam from the semiconductor laser 60 through the hole 103, changes the related laser beam to a parallel beam, and supplies the same to the optical device 700.

The base material 701 of the optical device 700 and the convex lens 702 have different refractive indexes from each other. The convex lens 702 receives the parallel beam from the optical device 100 and condenses the laser beam of the related parallel beam to the convex lens 122.

[0153]

The optical device 120 has the shape of a parallelopiped or substantial parallelopiped and can condense the beam emitted from the flat face of the convex lens 122 of the optical device 120 to the recording surface of an optical disc 80 when light from the convex lens 702 of the optical system 119 enters it.

[0154]

The optical system 129A has the optical devices 120 and 700. The combination of the optical devices 120 and 700 constitutes a solid immersion lens (SIL). By enlarging the refractive index of the convex lens 122, the numerical aperture NA of the optical system 129A can be made higher.

In the optical devices 100, 120, and 700, the convex lenses 102, 122, and 702 are formed by filling an optical

material in the concavities of the base materials, so the range of selection of the material of the convex lenses 102, 122, and 702 can be made larger, and an optical material having a large refractive index can be used as the material of the convex lenses.

[0155]

Sixth Embodiment of Optical System

Figure 23 is a schematic view of the configuration of a sixth embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 149B of Fig. 23, identical reference numerals are assigned to identical components as those of the optical system 119B of Fig. 20. Explanations of the identical components will be appropriately omitted. Also, in the optical system 149B of Fig. 23, the optical device 120 in Fig. 21 is used. The explanation of this optical device 120 will be appropriately omitted.

[0156]

This optical system 149B has optical devices 110, 120, and 710, the optical device 110 is stacked upon the optical device 120, and the optical device 710 is stacked upon the optical device 110.

The optical devices 110, 120, and 710 are bonded so that the optical axes of the convex lenses 112, 122, and 712 of the optical devices 110, 120, and 710 coincide or

substantially coincide.

[0157]

The optical system 119B has the optical devices 110 and 710. The base material 711 and the convex lens 712 of the optical device 710 are different in refractive index from each other.

The optical device 710 has the function of a collimator lens. The convex lens 712 changes the laser beam from the semiconductor laser to a parallel beam and supplies this to the optical device 110.

The convex lens 112 of the optical device 110 receives the parallel beam from the optical device 710 incident through the hole 113 and condenses the laser beam of the related parallel beam to the convex lens 122.

[0158]

The optical device 120 has the shape of a parallelopiped or substantial parallelopiped and can condense the beam emitted from the flat face of the convex lens 122 of the optical device 120 to the recording surface of an optical disc 80 when light from the convex lens 712 of the optical system 119B enters it.

[0159]

The optical system 129 has the optical devices 110 and 120. The combination of the optical devices 110 and 120 constitutes a solid immersion lens (SIL). By

enlarging the refractive index of the convex lens 122, the numerical aperture NA of the optical system 129 can be made higher.

In the optical devices 110, 120, and 710, the convex lenses 112, 122, and 712 are formed by filling an optical material in the concavities of the base materials, so the range of selection of the material of the convex lenses 112, 122, and 712 can be made large, and an optical material having a large refractive index can be used as the material of the convex lenses.

[0160]

Seventh Embodiment of Optical System

Figure 24 is a schematic view of the configuration of a seventh embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 159 of Fig. 24, identical reference numerals are assigned to identical components as those of the optical system 149 of Fig. 21. Explanation of the identical components will be appropriately omitted.

This optical system 159 is configured as the optical system 149 of Fig. 21 with an optical device 150 inserted as a beam splitter between the optical devices 100 and 110.

[0161]

The optical system 159 has the optical devices 100, 110, 120, and 150, the optical device 110 is stacked upon the optical device 120, the optical device 150 is stacked upon the optical device 110, and the optical device 100 is stacked upon the optical device 150. The optical devices 100, 110, 120, and 150 are bonded so that the optical axes of the convex lenses 102, 112, and 122 of the optical devices 100, 110, and 120 coincide or substantially coincide.

[0162]

The optical device 150 located between the optical devices 100 and 110 has the function of a beam splitter. A film of semi-transparency (semi-transparent film) 152 is located between the convex lenses 102 and 112.

This semi-transparent film 152 passes the parallel beam from (the convex lens 102 of) the optical device 100 therethrough and reflects a returned beam from (the convex lens 112 of) the optical device 110.

[0163]

The convex lens 102 of the optical device 100 is a collimator lens, changes the laser beam from the semiconductor laser 60 to a parallel beam, and supplies this parallel beam via the optical device 150 to the optical device 110 in the optical system 129.

[0164]

The optical system 129 emits the parallel beam from the optical device 150 through the lenses 112 and 122 from the bottom face of the convex lens 122, condenses the emitted beam to the recording surface of the optical disc 80, and irradiates the related recording surface. Also, the optical system 129 supplies the reflected laser beam reflected at

the recording surface of) the optical disc 80 (returned laser beam) to the optical device 150.

By interposing the optical device 150 as the beam splitter between the optical device 100 and the optical system 129, it is possible to extract the reflected laser beam reflected at the optical disc 80 from the side face of the optical device 150.

[0165]

Eighth Embodiment of Optical System

Figure 25 is a schematic view of the configuration of an eighth embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 159A of Fig. 25, identical reference numerals are assigned to identical components as those of the optical system 159 of Fig. 24 and the optical system 149A of Fig. 22. Explanation of the identical components will be appropriately omitted.

This optical system 159A is configured as the

optical system 149A of Fig. 22 with the optical device 150 inserted as a beam splitter between the optical devices 100 and 700.

[0166]

The optical system 159A has the optical devices 100, 120, 150, and 700, the optical device 700 is stacked upon the optical device 120, the optical device 150 is stacked upon the optical device 700, and the optical device 100 is stacked upon the optical device 150. The optical devices 100, 120, 150, and 700 are bonded so that the optical axes of the convex lenses 102, 122, and 702 of the optical devices 100, 120 and 700 coincide or substantially coincide.

[0167]

The optical device 150 located between the optical devices 100 and 700 has the function of a beam splitter. A film having semi-transparency (semi-transparent film) 152 is located between the convex lenses 102 and 702.

This semi-transparent film 152 passes the parallel beam from (the convex lens 102 of) the optical device 100 therethrough and reflects a returned beam from (the convex lens 702 of) the optical device 700.

[0168]

The convex lens 102 of the optical device 100 is a collimator lens, changes the laser beam from the

semiconductor laser 60 to a parallel beam, and supplies this parallel beam via the optical device 150 to the optical device 700 in the optical system 129A.

[0169]

The optical system 129A emits the parallel beam from the optical device 150 through the lenses 702 and 122 from the bottom face of the convex lens 122, condenses the emitted beam to the recording surface of the optical disc 80, and irradiates the related recording surface. Also, the optical system 129A supplies the reflected laser beam reflected at (the recording surface of) the optical disc 80 (returned laser beam) to the optical device 150.

By interposing the optical device 150 as the beam splitter between the optical device 100 and the optical system 129A, it is possible to extract the reflected laser beam reflected at the optical disc 80 from the side face of the optical device 150.

[0170]

<u>Ninth Embodiment of Optical System</u>

Figure 26 is a schematic view of the configuration of a ninth embodiment of an optical system using optical devices according to the present invention. Note that in an optical system 159B of Fig. 26, identical reference numerals are assigned to identical components as those of

the optical system 159 of Fig. 24 and the optical system 149B of Fig. 23. Explanations of the identical components will be appropriately omitted.

This optical system 159B is configured as the optical system 149B of Fig. 23 with the optical device 150 inserted as a beam splitter between the optical devices 110 and 710.

[0171]

The optical system 159B has the optical devices 110, 120, 150, and 710, the optical device 110 is stacked upon the optical device 120, the optical device 150 is stacked upon the optical device 110, and the optical device 710 is stacked upon the optical device 150. The optical devices 110, 120, 150, and 710 are bonded so that the optical axes of the convex lenses 112, 122, and 712 of the optical devices 110, 120 and 710 coincide or substantially coincide.

[0172]

The optical device 150 located between the optical devices 110 and 710 has the function of a beam splitter. A film having semi-transparency (semi-transparent film) 152 is located between the convex lenses 112 and 712.

This semi-transparent film 152 passes the parallel beam from (the convex lens 712 of) the optical device 710 therethrough and reflects the returned beam from (the

convex lens 112 of) the optical device 110.

[0173]

The optical device 710 has the function of a collimator lens, changes the laser beam from the semiconductor laser 60 to the parallel beam, and supplies this parallel beam via the optical device 150 to the optical device 110 in the optical system 129.

[0174]

The optical system 129 emits the parallel beam from the optical device 150 through the convex lenses 112 and 122 from the bottom face of the convex lens 122, condenses the emitted beam to the recording surface of the optical disc 80, and irradiates the related recording surface. Also, the optical system 129 supplies the reflected laser beam reflected at (the recording surface of) the optical disc 80 (returned laser beam) to the optical device 150.

By interposing the optical device 150 as the beam splitter between the optical device 710 and the optical system 129, it is possible to extract the reflected laser beam reflected at the optical disc 80 from the side face of the optical device 150.

[0175]

<u>Optical Head</u>

Figure 27 is a schematic view of the configuration

of an embodiment of an optical head using optical devices according to the present invention.

This optical head 600 has an optical system 329, an IC chip 74, a prism 75, and an optical device 340. A flying head (floating type optical head) is comprised by a swing arm 72 and a suspension 73.

[0176]

The optical system 329 has optical devices 300 and 320. The optical device 300 is stacked upon the optical device 320. This optical system 329 comprises a slider. A bottom face 320B of the optical device 320 of the optical system 329 and the surface of the optical disc 80 face each other. The bottom face 320B of the optical device 320 comprises a slider face.

[0177]

The suspension 73 is attached to the lower face (bottom face) of the swing arm 72, or the suspension 73 is formed there.

Also, the upper face of the IC chip 74 is bonded to the front end of the lower face of the swing arm 72.

[0178]

The upper face of the prism 75 and the upper face of a base 76 are bonded to the lower face of the IC chip 74.

The upper face of the optical device 340 is bonded to the lower face of the prism 75.

A flexible optical fiber 71 is bonded to the lower face of the base 76. For example, a V-shaped groove is formed in the lower face of the base 76, and the optical fiber 71 is tightly fixed so that the optical fiber 71 is fit in the related V-shaped groove. Note that desirably the base 76 is made of an identical material to the IC chip 74.

The optical system 329 is attached to the front end of the suspension 73.

[0179]

The optical device 340 is shaped as a parallelopiped or a substantial parallelopiped provided with a hole 343. The optical device 340 has a base material (substrate) 341 and a convex lens 342.

In the base material 341, a concave curved face (concretely the annular inclined face) 341C closely contacting the convex curved face of the convex lens 342 is formed in a lower face 340B. At the same time, the hole 343 communicating with an upper face 340U is formed from the deep side of the concave curved face 341C.

Then, part (concretely the center portion) of the convex curved face of the convex lens 342 is exposed in the hole 343 of the base material 341.

[0180]

The convex lens 342 is a collimator lens and has a

rotationally symmetric or substantially rotationally symmetric shape surrounded by the flat face and the convex curved face facing this flat face. The optical axis of the convex lens 342 or the extension thereof passes through the hole 343. The shape of the convex curved face when the convex lens 342 is cut along its symmetry axis is preferably made an arc or substantially arc.

The hole 343 has a rotationally symmetric or substantially rotationally symmetric shape, and the symmetry axis of the hole 343 and the optical axis of the convex lens 342 coincide or substantially coincide.

[0181]

The flat face of the convex lens 342 is parallel or substantially parallel to the upper face 340U of the optical device 340 (or the upper face of the base material 341). Also, the flat portion (or flat face) on the area around the concave curved face 341C in the lower face 340B of the base material 341 and the flat face of the convex lens 342 are parallel or substantially parallel and located in an identical plane in Fig. 27.

[0182]

The optical device 340 has the shape of a parallelopiped or substantial parallelopiped and can change a beam emitted from the lower face 340B of the

optical device 340 to a parallel beam by the convex lens 342 when light enters the upper face 340U.

[0183]

A half mirror is formed on the inclined face of the prism 75. This half mirror reflects the laser beam radiated from an end face of the optical fiber 71 and supplies the same to the optical device 340.

The optical device 340 supplies the laser beam from the half mirror of the prism 75 to the convex lens 342 through the hole 343. The convex lens 342 changes the laser beam from the half mirror to a parallel beam and supplies the same to the optical system 329.

[0184]

The optical system 329 condenses the laser beam from the optical device 340 to the optical disc 80 by using lenses 302 and 322 and focuses it on the recording surface of the optical disc 80. Also, the optical system 329 returns the laser beam reflected at the recording surface of the optical disc 80 (returned laser beam) to the prism 75 via the convex lens 342 and the hole 343 of the optical device 340.

The half mirror of the inclined face of the prism 75 transmits the returned laser beam from the optical system 329 therethrough and supplies the same to the IC chip 74.

[0185]

The IC chip 74 is an optical semiconductor composite device. A photo-detector and an processing circuit are formed on the lower face of the IC chip 74, or the photo-detector and the processing circuit are attached there.

The photo-detector receives the returned laser beam and supplies a reception light signal in accordance with the returned laser beam to the processing circuit.

The processing circuit performs the predetermined processing based on the reception light signal from the photo-detector and creates a signal indicating the processing result. This signal can be extracted from a signal line connected to the IC chip 74.

[0186]

Figure 28 is a schematic view of the configuration of the optical system 329 in Fig. 7.

The optical system 329 has the optical devices 300 and 320.

The optical device 320 has a base material 321 and a convex lens 322. The base material 321 is made of an optical material. The base material 321 and the convex lens 322 are different in refractive index from each other.

[0187]

The base material 321 has a rotationally symmetric or substantially rotationally symmetric concavity 321B in

the lower face of the base material 321. The shape of the surface of the concavity 321B when the concavity 321B is cut along its symmetry axis is preferably made an arc or substantially arc.

The concavity 321B is filled with an optical material having a different refractive index from the base material 321. The convex lens 322 is comprised of the concavity 321B filled with the related optical material.

[0188]

The lower face of the convex lens 322 is flat and is parallel or substantially parallel to an upper face 320U of the optical device 320 (or the upper face of the base material 321). Also, the flat portions of the lower face of the convex lens 322 and the lower face 320B of the base material 321 are located in the identical plane and comprise the lower face of the optical device 320.

[0189]

The optical device 320 exhibits the shape of a parallelopiped or substantial parallelopiped and can converge (condense) the beam emitted from the flat face of the convex lens 322 when light enters the upper face 320U.

The lower face 300B of the optical device 300 (or base material 301) and the upper face 320U of the optical

device 320 are bonded so that the optical axes of the convex lenses 302 and 322 coincide or substantially coincide.

Note that, by rounding the edges of the bottom face 320B of the optical device 320 (face facing the optical disc 80), it is possible to reduce collisions with and/or shock to the surface of the optical disc 80.

[0190]

It is also possible if the base material 321 of the optical device 320 is made for example aluminum oxide or silicon nitride.

The optical system 329 of the optical head 600 desirably has a large rigidity and/or hardness. By forming the base material 321 of the optical device 320 by aluminum oxide, the rigidity and/or hardness can be increased.

A high numerical aperture can be obtained by the optical system 329. By comprising a solid immersion lens (SIL) by the optical system 329 and using the related optical system 329 in the near field region, it is possible to perform near field optical recording and/or reproduction and it is possible to improve a recording density of the optical disc.

[0191]

It is also possible to form rails for floating the

optical system 329 as the slider on the bottom face 320B of the optical device 320.

It is also possible to form on the bottom face 320B of the optical device 320 a coil generating a magnetic field (or a magnetic flux) at the time of opto-magnetic recording when the optical disc 80 is an opto-magnetic disc.

It is also possible to easily prepare the rails and/or coil of the bottom face 320B of the optical device 320 by forming the optical device 320 in a parallelopiped or substantially parallelopiped or plate-like or substantially plate-like shape by utilizing a semiconductor manufacturing process.

[0192]

As an example, the size of the optical system 329 in a lateral direction is made about 1 mm, the size in a vertical direction is made about 0.5 mm, and the size in a height direction is made about 0.4 mm.

As an example, the size of the optical device 300 in the height direction is made about 0.3 mm, and the size of the optical device 320 in the height direction is made about 0.13 mm.

As an example, a diameter of the bottom face (or the flat face) of the lens 302 is made about 0.2 mm, and the diameter of the bottom face (or the flat face) of the

lens 322 is made about 0.1 mm.

[0193]

Figure 29 is a schematic explanatory view of an example of the configuration of the IC chip 74 in Fig. 27 and the periphery thereof.

To the IC chip 74 receives drive power from a not illustrated power supply line. Also, the IC chip 74 can extract an output signal of the IC chip 74 by a flexible signal line 79, and can supply the signal to the IC chip 74. Note the signal line 79 may also be configured as an ultra-fine wire of a metal of copper or the like given a thin insulative coating.

[0194]

The upper face of the prism 75 and the upper face of the base (sub mount) 76 are bonded to the lower face of the IC chip 74. The optical fiber 71 is bonded to the lower face of the base 76.

A half mirror 78 is formed on the inclined face of the prism 75. The half mirror 78 reflects the laser beam radiated from the end face of the optical fiber 71 and supplies the same to the convex lens 342 of the optical device 340.

The laser beam passed through the convex lens 342 is irradiated to the optical disc 80 via the optical system 329, reflected at the recording surface of the optical

fiber 80, and returned to the convex lens 342.

[0195]

The half mirror 78 transmits the returned laser beam from the convex lens 342 therethrough and supplies the same to the inclined face of the prism 75. The inclined face of the prism 75 supplies the returned laser beam transmitted through the half mirror 78 to the IC chip 74.

Note that the half mirror 78 is comprised by a multi-layer film reflecting the laser beam from the direction of the end face of the optical fiber 71 and transmitting the laser beam from the direction of the convex lens 342 therethrough.

[0196]

A photo-detector 77 is formed on the lower face of the IC chip 74. This photo-detector 77 has first and second photo-detectors 77A and 77B.

The returned laser beam transmitted through the inclined face of the prism 75 is condensed onto the second photo-detector 77B and reflected, reflected again at the lower face of the prism 75, and condensed onto the first photo-detector 77A. Note that a not illustrated reflection film is formed on the lower face of the prism 75.

The IC chip 74 supplies the output signals from the photo-detectors 77A and 77B to the processing circuit in

the IC chip 74.

[0197]

By comprising the photo-detector 77 as a six-divided photo-detector and comprising the photo-detectors 77A and 77B as three-divided photo-detectors, a focus error signal can be created by a D-3DF (difference - 3 Divided Focusing), a tracking error signal can be created by a push pull method, and the reproduction signal can be created by a sum of the output signals of the photo-detector 77A or the photo-detector 77B.

Further, the IC chip 74 can fetch the focus error signal, tracking error signal, and reproduction signal from the signal line 79.

[0198]

In the optical head 600 of Fig. 27, a reduction of the size of the optical head is possible in comparison with an optical head provided with a semiconductor laser, and it is possible to quickly move the optical head.

For example, in order to provide a semiconductor laser in the optical head, heat dissipating parts for countering the heat generation of the semiconductor laser, a sealed vessel for protecting the semiconductor laser, etc. are necessary, but in the optical head 600, the heat dissipation parts and sealed vessel are unnecessary. A reduction of size is possible in this

point.

In this way, by using the light weight and small sized optical head 600, reduction of size of the optical disc apparatus is possible, and high speed access to the optical disc 80 is possible.

[0199]

Also, in the optical head 600, since the reflected laser beam from the optical disc 80 (returned laser beam) is converted to an electric signal, it becomes unnecessary to send the returned laser beam to the optical fiber 71. Accordingly, a highly precise arrangement of the parts for sending the returned laser beam into the optical fiber 71 becomes unnecessary, so an optical head 600 which can be easily manufactured can be obtained.

Further, an optical head 600 having a high reliability against a vibration and high signal quality can be obtained.

[0200]

Note that the refractive index of the glass used in the mold lens is 1.4 to 1.7 as an example.

As the optical material of the optical device according to the present invention, particularly the optical material having a large refractive index (or a high refractive index) filled in the concavity of the

base material, use can be made of for example aluminum oxide (Al_2O_3 having a refractive index of for example about 1.8), titanium oxide (TiO_2 having a refractive index of for example about 2.5), tantalum oxide (Ta_2O_5 having a refractive index of about 2.4), or gallium phosphate (GaP having a refractive index of for example about 3.3) By using the above optical materials, an optical device having a large numerical aperture can be prepared.

[0201]

Also, as the optical material of the optical device according to the present invention, particularly the optical material filled in the concavity of the base material, use can be made of compounds such as $Ta_{X1}O_{Y1}$, $Ti_{X2}O_{Y2}$, $Al_{X3}O_{Y3}$, $Si_{X4}O_{Y4}$, $Si_{X5}N_{Y5}$, $Mg_{X6}F_{Y6}$, $Ga_{X7}N_{Y7}$, $Ga_{X8}P_{Y8}$, $Ti_{X9}Nb_{Y9}O_{Z9}$, and $Ti_{Z6}Ta_{Z7}O_{Z8}$. Note X1 to X9, Y1 to Y9, and Z6 to Z9 are numerals enabling the above compounds.

[0202]

Note that the above embodiments are illustrations of the present invention. The present invention is not limited to the above embodiments.

[0203]

[Effects of the Invention]

As explained above, according to the method of production of an optical device according to the present

invention, it is possible to prepare a small sized optical device. Also, according to the method of production of an optical device according to the present invention, it is possible to prepare an optical device having a small size and large numerical aperture.

Also, according to the present invention, an optical device which can be prepared from the above method of production and an optical system using the related optical device can be provided.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

A schematic view of the configuration of an embodiment of an optical device according to the present invention.

[Fig. 2]

A schematic explanatory view of a first embodiment of a method of production of an optical device according to the present invention.

[Fig. 3]

A schematic explanatory view of the first embodiment of the method of production of an optical device according to the present invention continuing from Fig. 2.

[Fig. 4]

A schematic explanatory view of the first embodiment

of the method of production of an optical device according to the present invention continuing from Fig. 3.

[Fig. 5]

A schematic explanatory view of a second embodiment of the method of production of an optical device according to the present invention.

[Fig. 6]

A schematic explanatory view of the second embodiment of the method of production of an optical device according to the present invention continuing from Fig. 5.

[Fig. 7]

A schematic explanatory view of the second embodiment of the method of production of an optical device according to the present invention continuing from Fig. 6.

[Fig. 8]

A schematic explanatory view of a third embodiment of the method of production of an optical device according to the present invention.

[Fig. 9]

A schematic explanatory view of the third embodiment of the method of production of an optical device according to the present invention continuing from Fig.

8.

[Fig. 10]

A schematic explanatory view of the third embodiment of the method of production of an optical device according to the present invention continuing from Fig. 9.

[Fig. 11]

A schematic explanatory view of a fourth embodiment of the method of production of an optical device according to the present invention.

[Fig. 12]

A schematic explanatory view of the fourth embodiment of the method of production of an optical device according to the present invention continuing from Fig. 11.

[Fig. 13]

A schematic explanatory view of the fourth embodiment of the method of production of an optical device according to the present invention continuing from Fig. 12.

[Fig. 14]

A schematic explanatory view of a fifth embodiment of the method of production of an optical device according to the present invention.

[Fig. 15]

A schematic explanatory view of the fifth embodiment of the method of production of an optical device according to the present invention continuing from Fig. 14.

[Fig. 16]

A schematic explanatory view of a sixth embodiment of the method of production of an optical device according to the present invention.

[Fig. 17]

A schematic explanatory view of the sixth embodiment of the method of production of an optical device according to the present invention continuing from Fig. 16.

[Fig. 18]

A schematic view of the configuration of a first embodiment of an optical system using optical devices according to the present invention.

[Fig. 19]

A schematic view of the configuration of a second embodiment of an optical system using optical devices according to the present invention.

[Fig. 20]

A schematic view of the configuration of a third embodiment of an optical system using optical devices according to the present invention.

[Fig. 21]

A schematic view of the configuration of a fourth embodiment of an optical system using optical devices according to the present invention.

[Fig. 22]

A schematic view of the configuration of a fifth embodiment of an optical system using optical devices according to the present invention.

[Fig. 23]

A schematic view of the configuration of a sixth embodiment of an optical system using optical devices according to the present invention.

[Fig. 24]

A schematic view of the configuration of a seventh embodiment of an optical system using optical devices according to the present invention.

[Fig. 25]

A schematic view of the configuration of an eighth embodiment of an optical system using optical devices according to the present invention.

[Fig. 26]

A schematic view of the configuration of a ninth embodiment of an optical system using optical devices according to the present invention.

[Fig. 27]

A schematic view of the configuration of an embodiment of an optical head using the optical device according to the present invention.

[Fig. 28]

A schematic view of the configuration of an optical system 329 in Fig. 27.

[Fig. 29]

Fig. 29 is a schematic explanatory view of an example of the configuration of an IC chip in Fig. 27 and the periphery thereof.

[Description of References]

3... metallic mold, 4... passageway, 5, 8U, 10U... projections, 6, 11, 21, 31, 41, 51, 86, 101, 111, 121, 301, 321... base materials, 6B, 7B, 10B, 20B, 27U, 31U, 41U, 51U, 86B, 101B, 111B, 701B, 711B... concavities, 6L, 6M, 10M, 11M, 20M, 21M, 31M, 41M, 86M... materials, 7M, 27M, 37M... optical materials, 7, 10, 20, 27, 37, 87... layers, 8, 18... silicon substrates, 9, 19... resists, 10S, 100U, 110U, 120U... upper faces, 32... etching solution, 29, 50, 52, 54, 56, 58... resist films, 29H, 50H, 52H, 54H, 56H, 58H... windows, 51, 53, 55, 57, 59, 103, 113, 303, 343... holes, 60... semiconductor laser, 71... optical fiber, 72... swing arm, 73... suspension, 74... IC chip, 75... prism, 76... base, 77, 77A, 77B... photo-detectors, 78... half mirror, 79... signal line,

80... optical disc, 85... coating film, 100, 110, 120, 340, 700, 710... optical devices, 100B, 110B, 120B... lower faces, 6C, 10C, 20C, 31C, 41C, 86C, 101C, 111C, 301C, 341C... concave curves, 102, 112, 122, 302, 322, 342, 702, 712... convex lenses, 7C, 27C, 37C, 87C, 102C, 112C, 302C... convex curves, 119, 119A, 119B, 129, 129A, 149, 149A, 159, 159A, 329... optical systems, 150... optical device (beam splitter), and 600... optical head.

DOCUMENT NAME DRAWINGS

Fig. 1

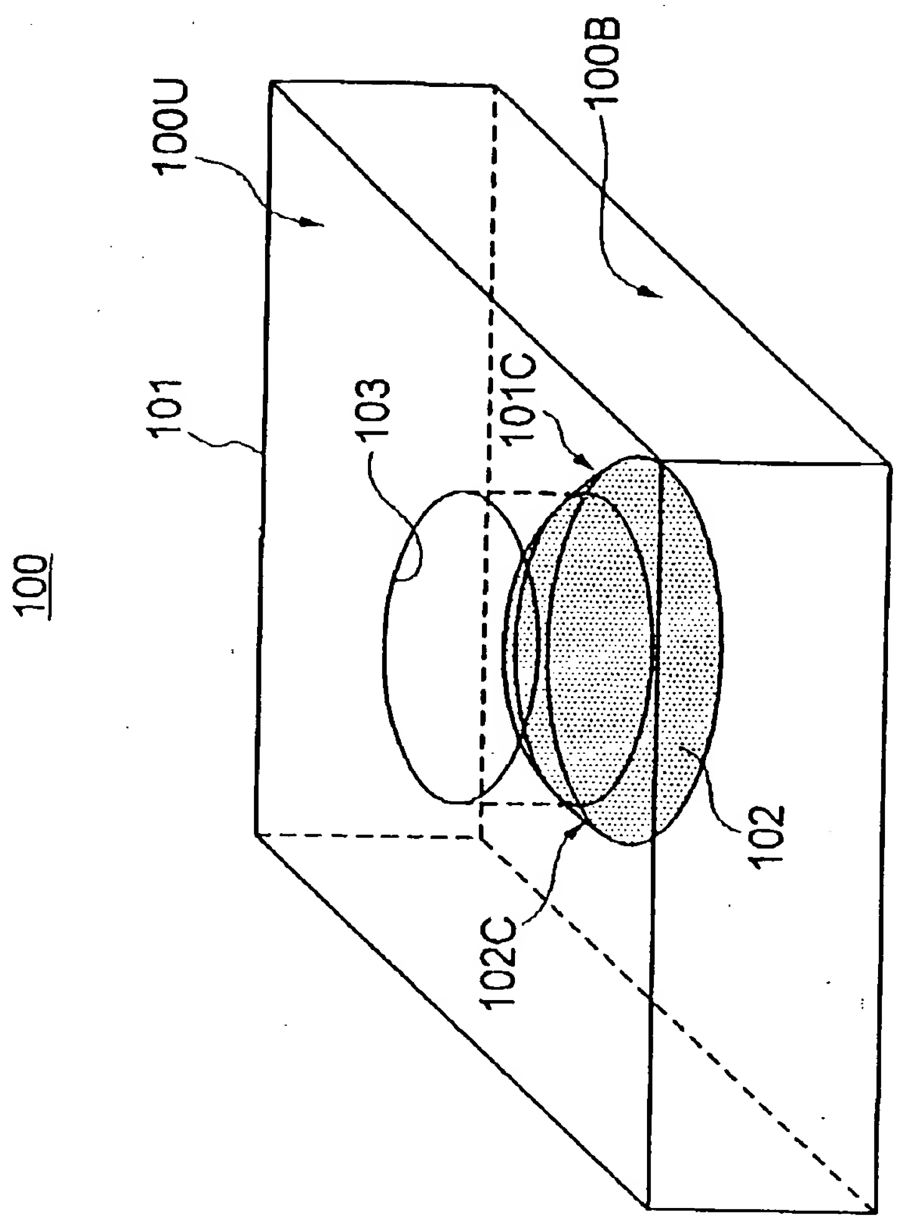


Fig. 2

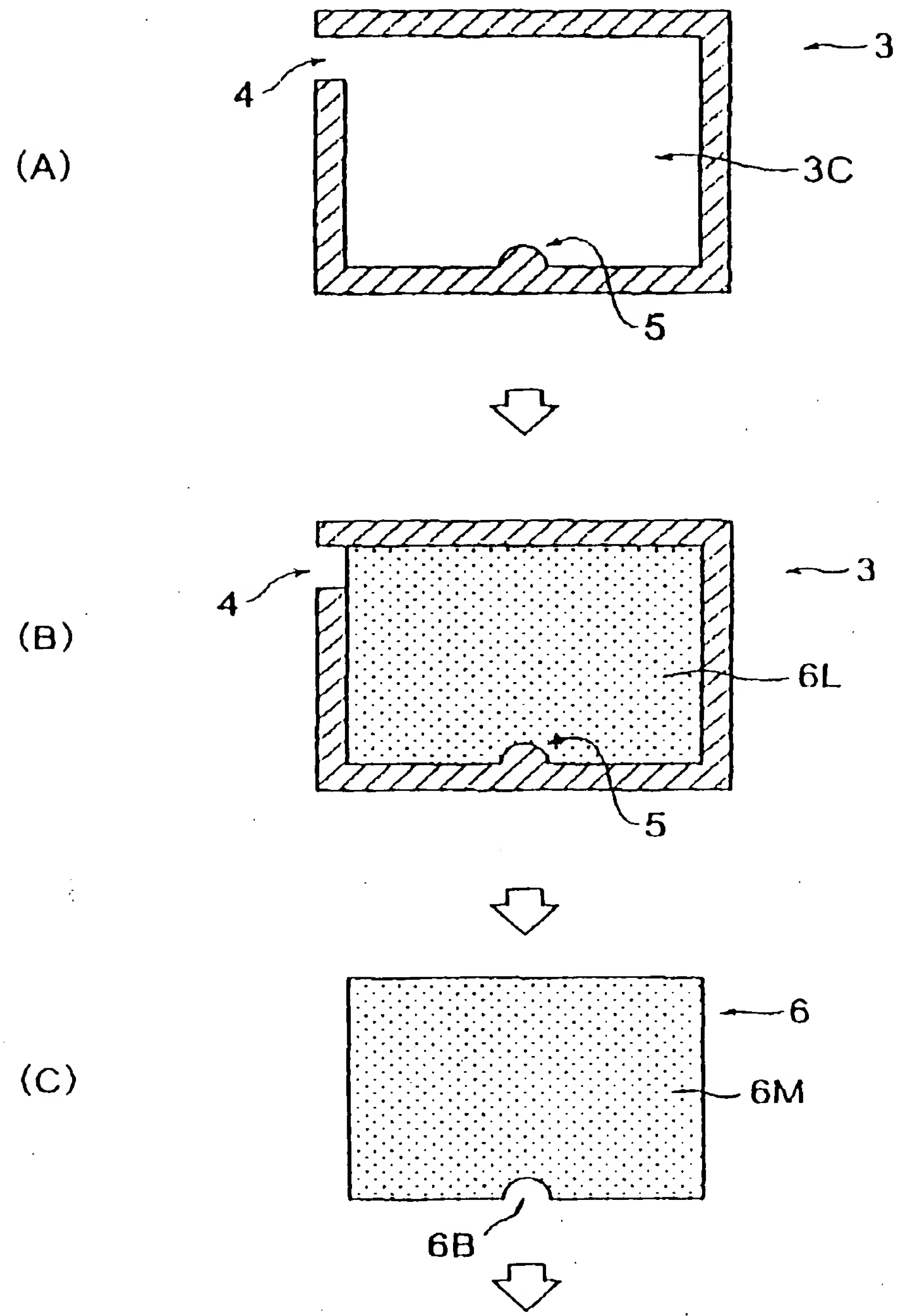
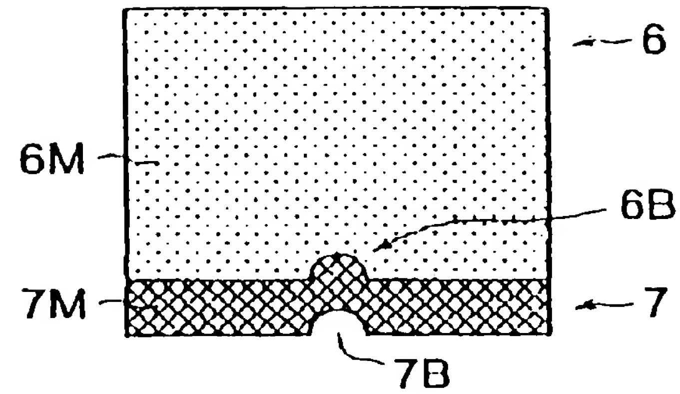


Fig. 3

(D)



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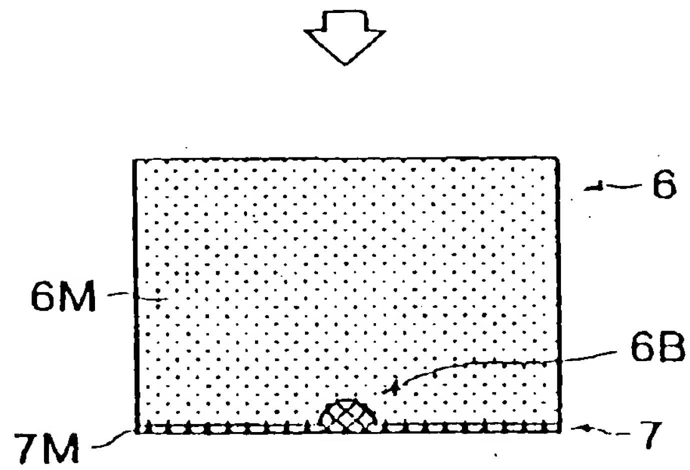
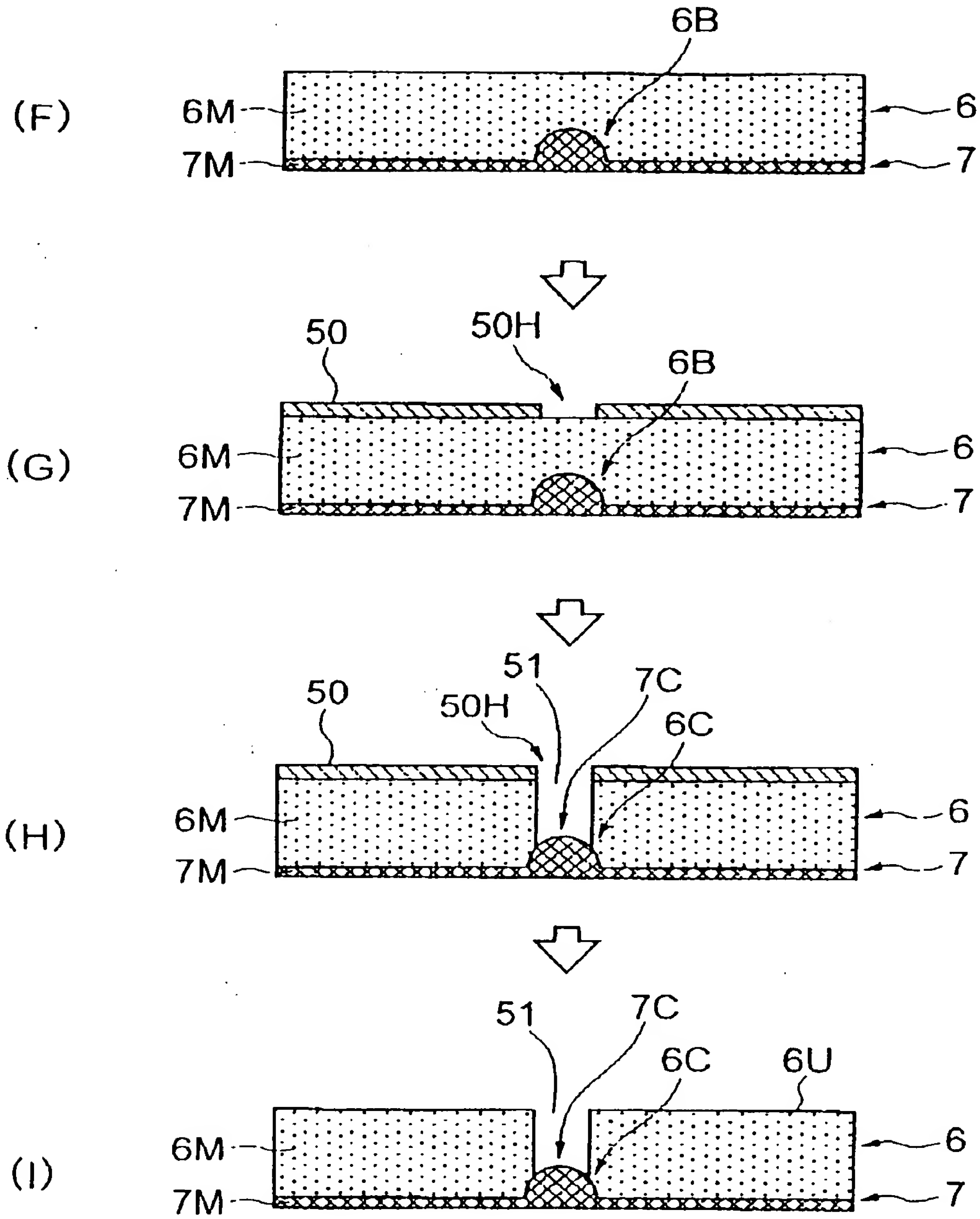


Fig. 4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7M
6
7
(G)
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50H
6B
6M
7M
6
7
(H)
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7C
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7M
6
7

Fig. 5

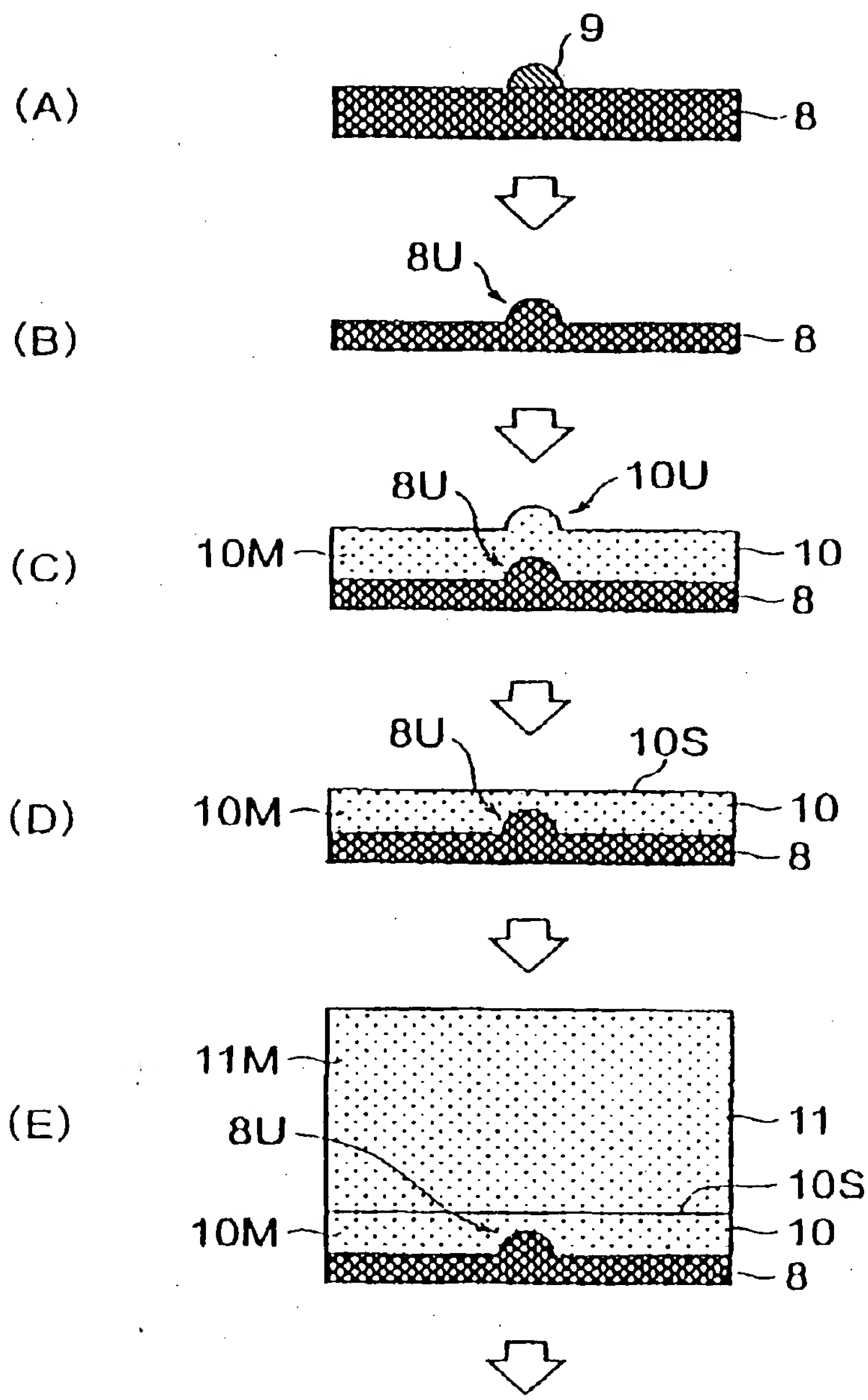
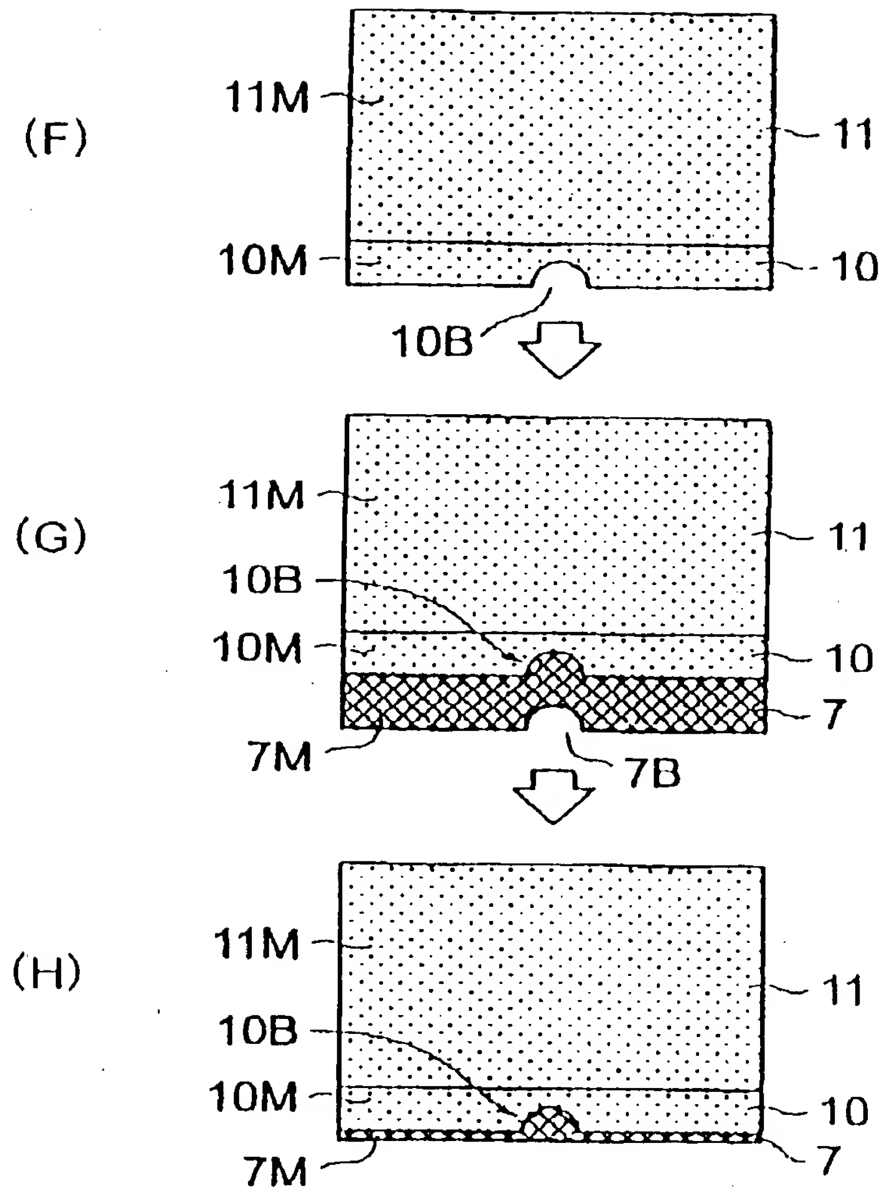


Fig. 6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10B
(G)
11M
11
10B
10M
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7M
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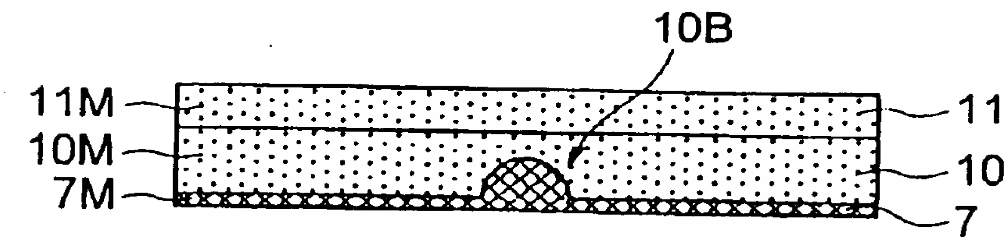
(H)
11M
11
10B
10M
10
7M
7

Fig. 7

(I)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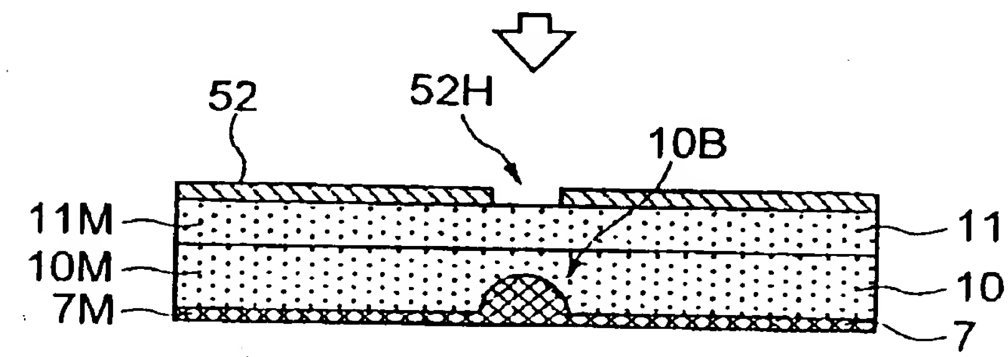
10M
7M
11
10
7

(J)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52H
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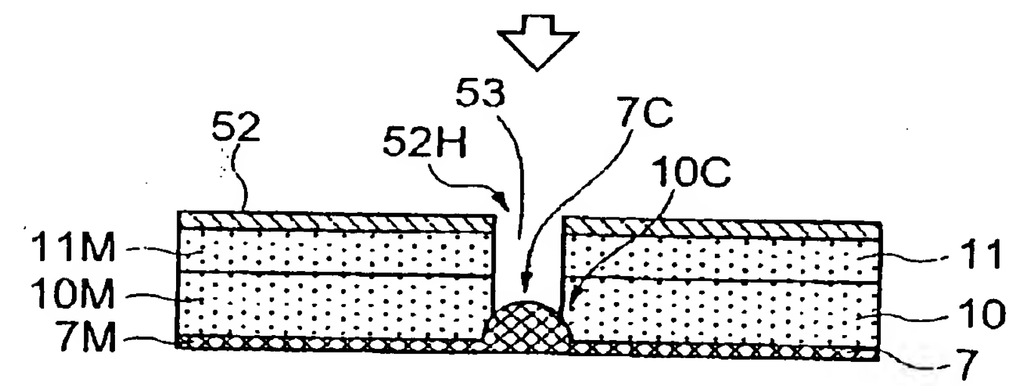
10M
7M
11
10
7

(K)


53
7C
52
52H
10C
11M
10M
7M
11
10
7

(L)

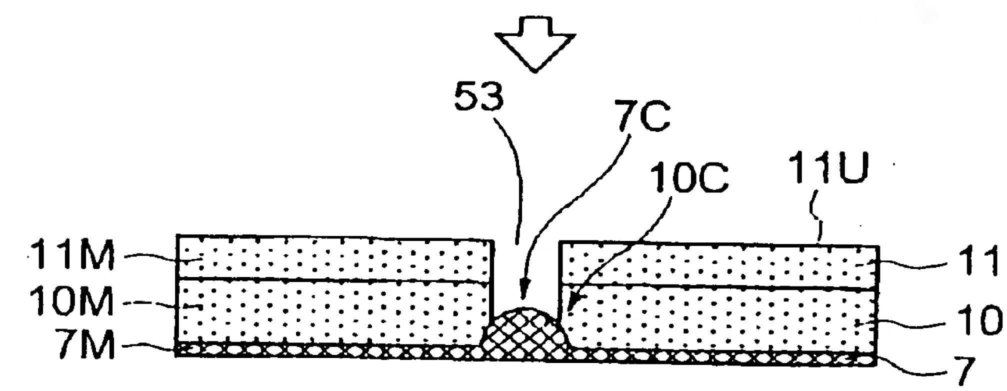

53
7C
10C
11U
11M
10M
7M
11
10
7

Fig. 8

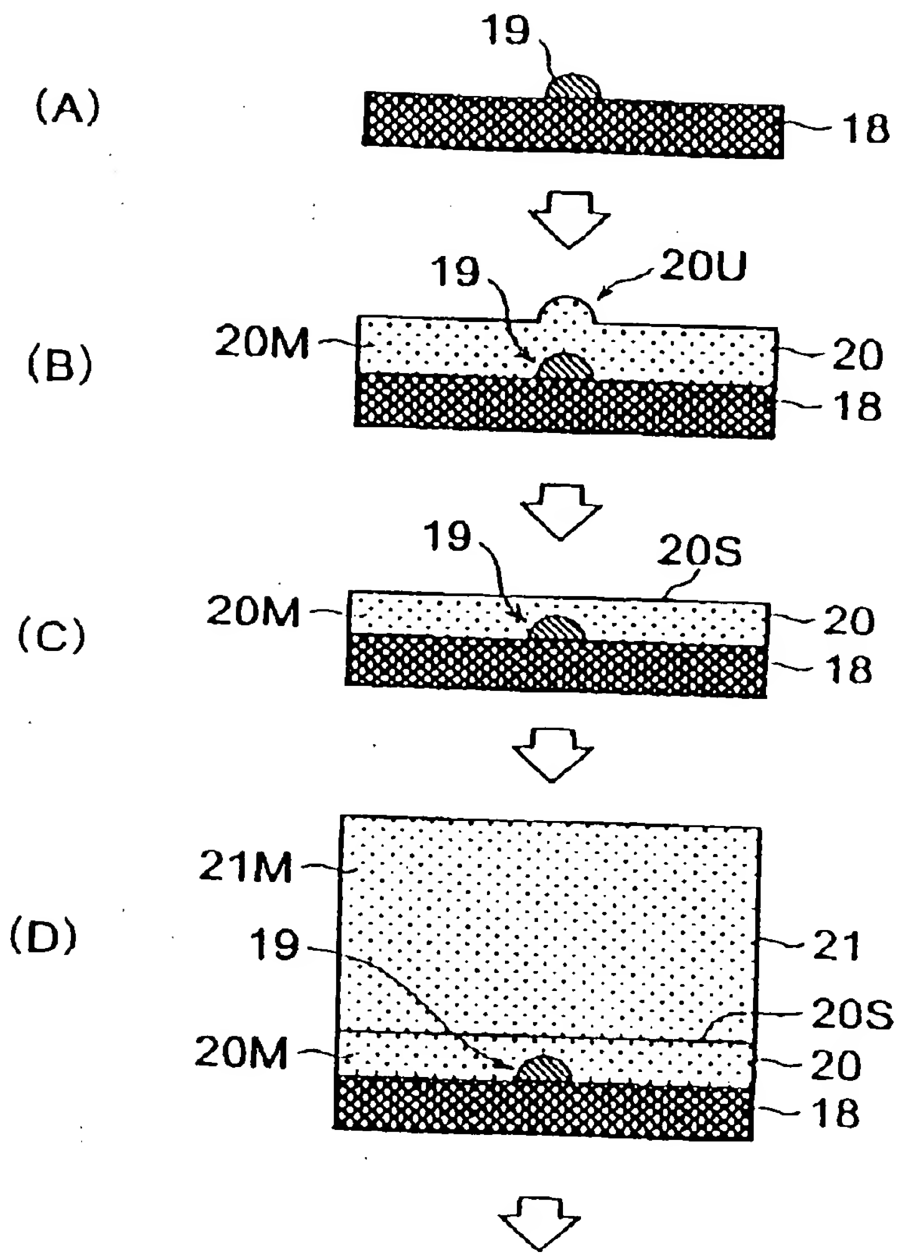


Fig. 9

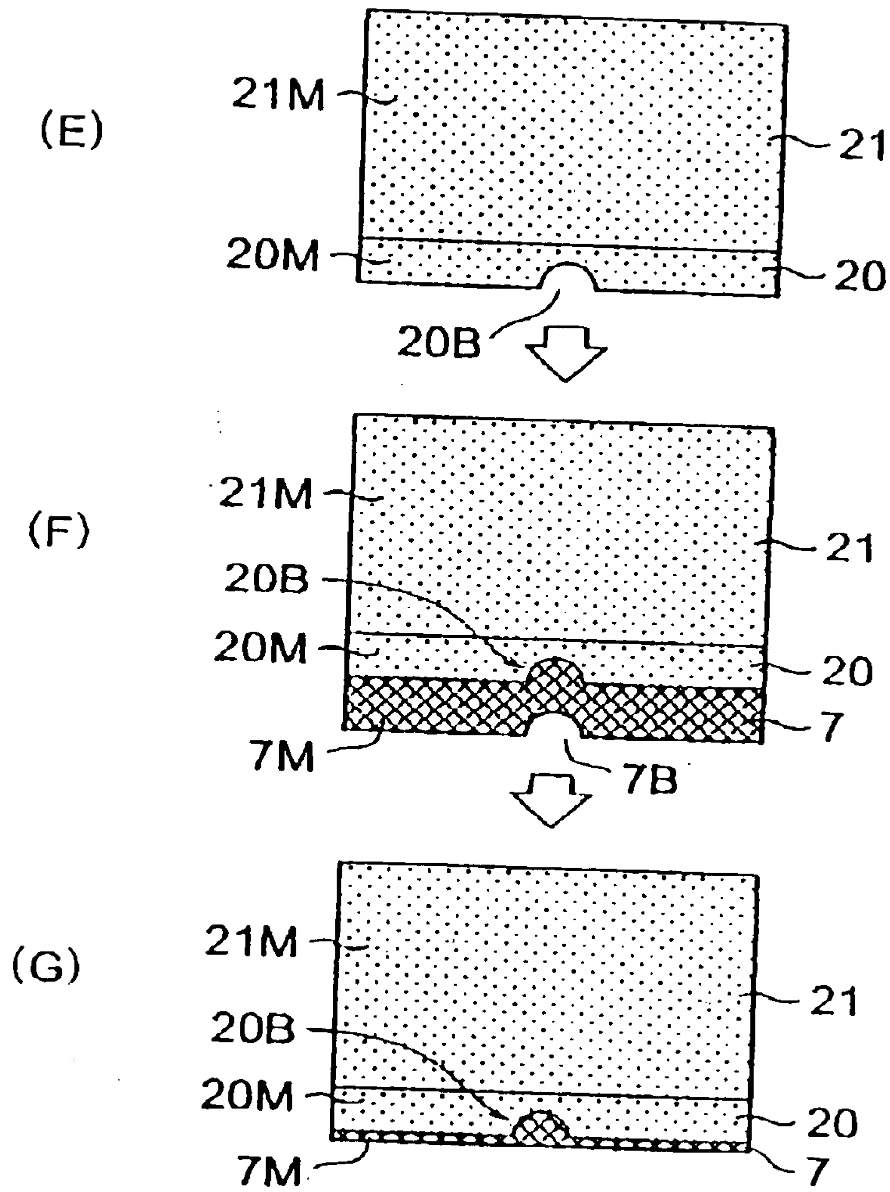

(E)
21M
21
20M
20
20B
(F)
21M
21
20B
20M
20
7
7M
7B
(G)
21M
21
20B
20M
20
7M
7

Fig. 10

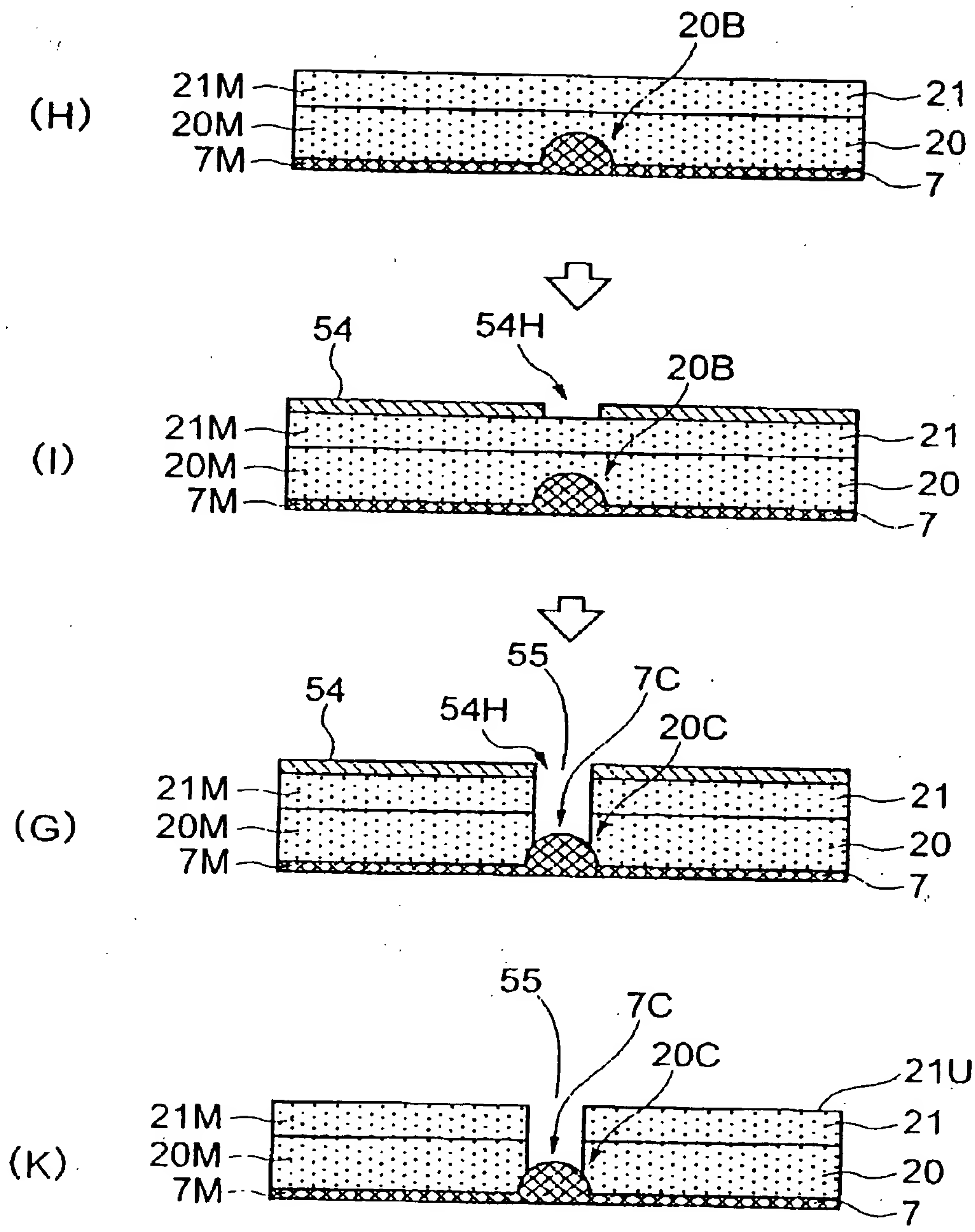

(H)
20B
21M
20M
7M
21
20
7
(I)
54
54H
20B
21M
20M
7M
21
20
7
(G)
55
54
7C
54H
20C
21M
20M
7M
21
20
7
(K)
55
7C
20C
21U
21M
20M
7M
21
20
7

Fig. 11

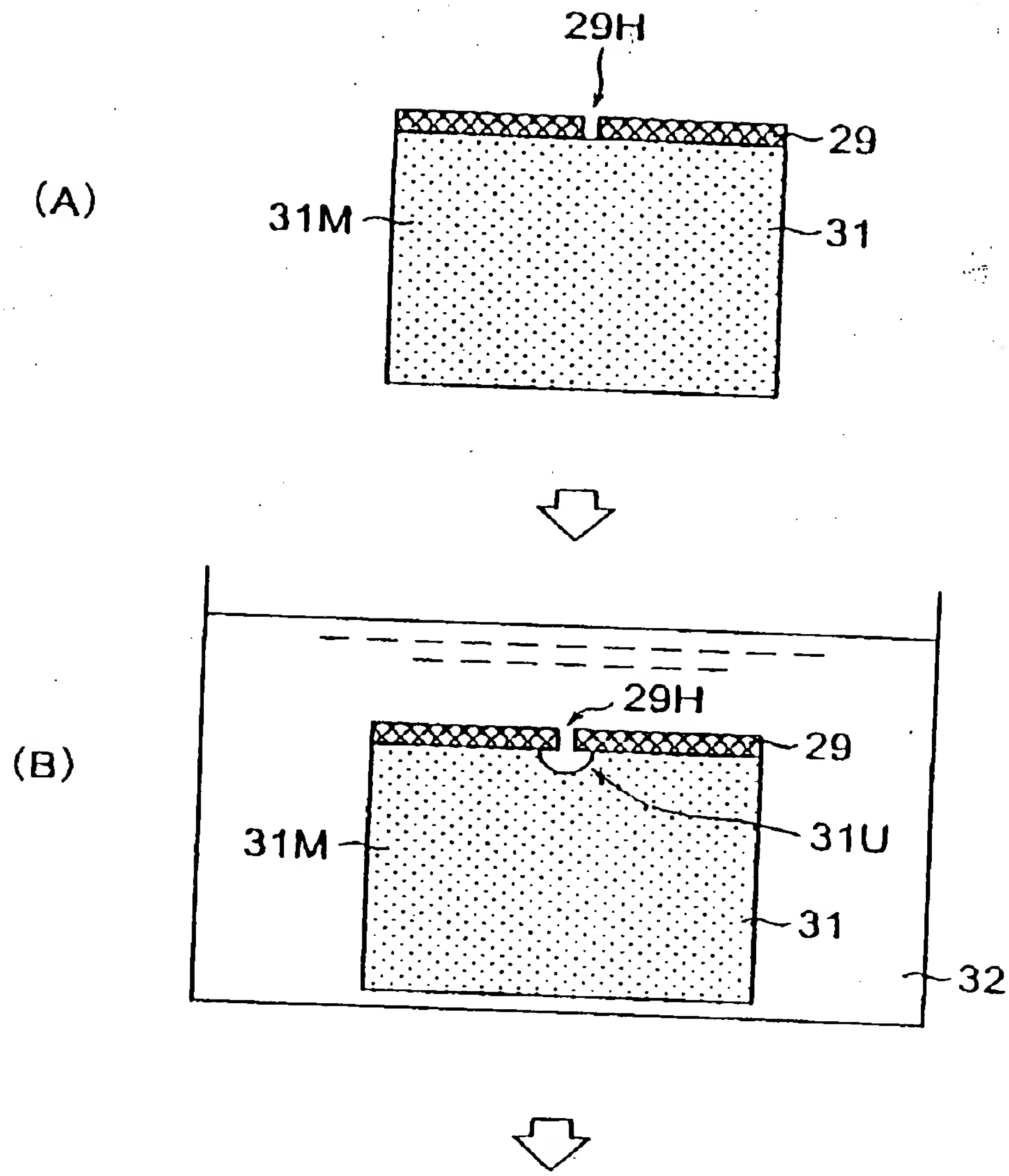


Fig. 12

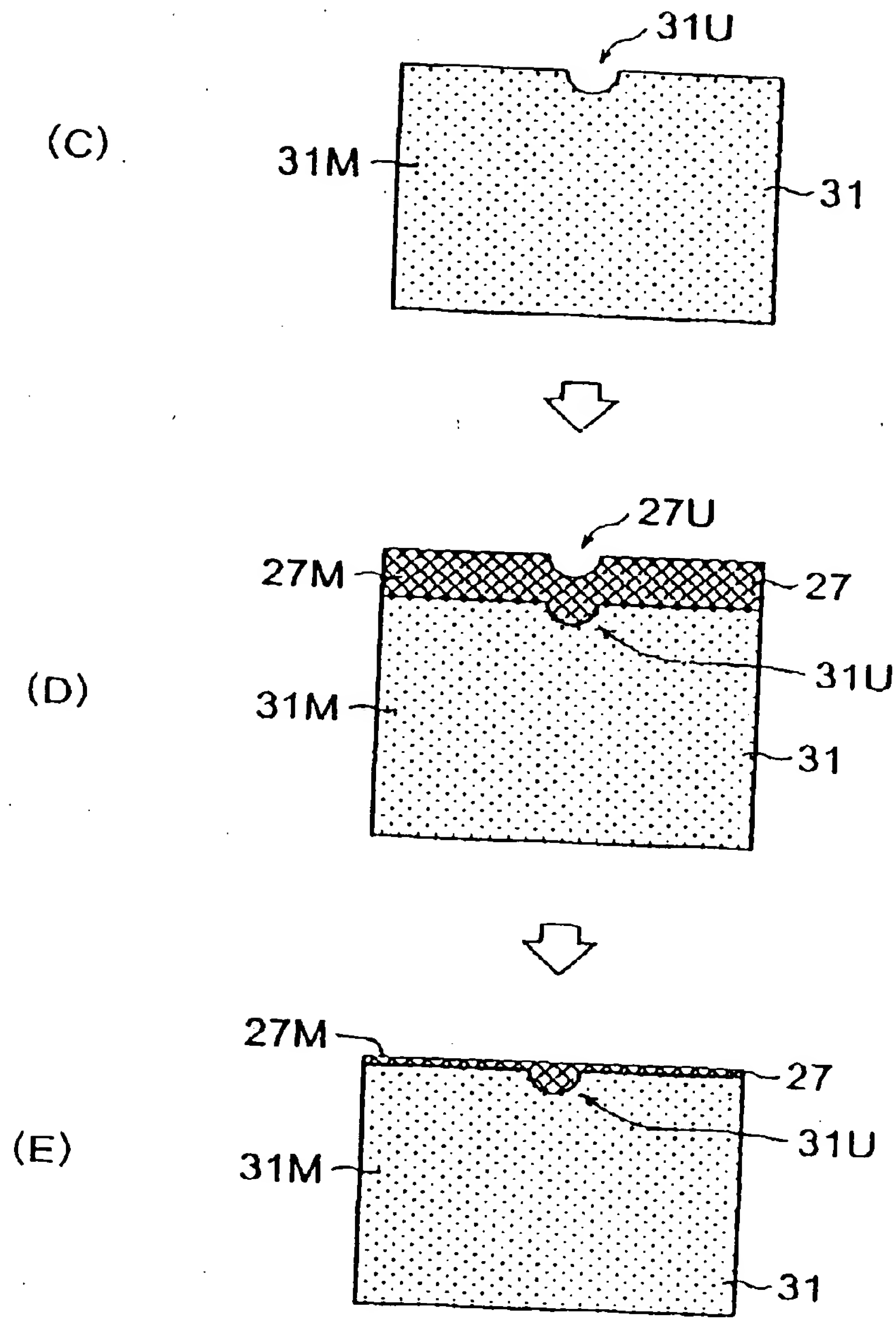


Fig. 13

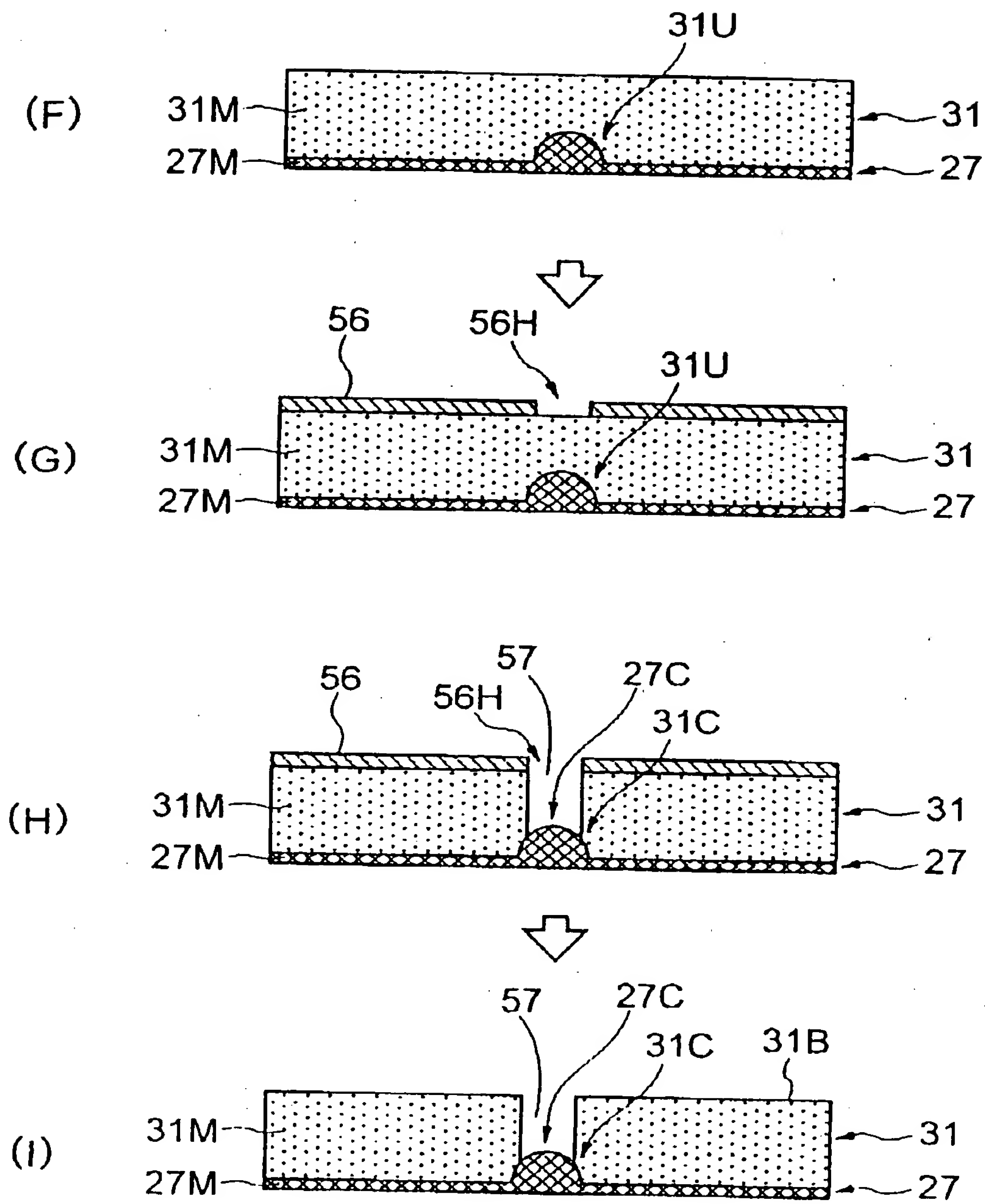

(F)
31U
31M
27M
31
27
(G)
56
56H
31U
31M
27M
31
27
(H)
57
56
56H
27C
31C
31M
27M
31
27
(I)
57
27C
31C
31B
31M
27M
31
27

Fig. 14

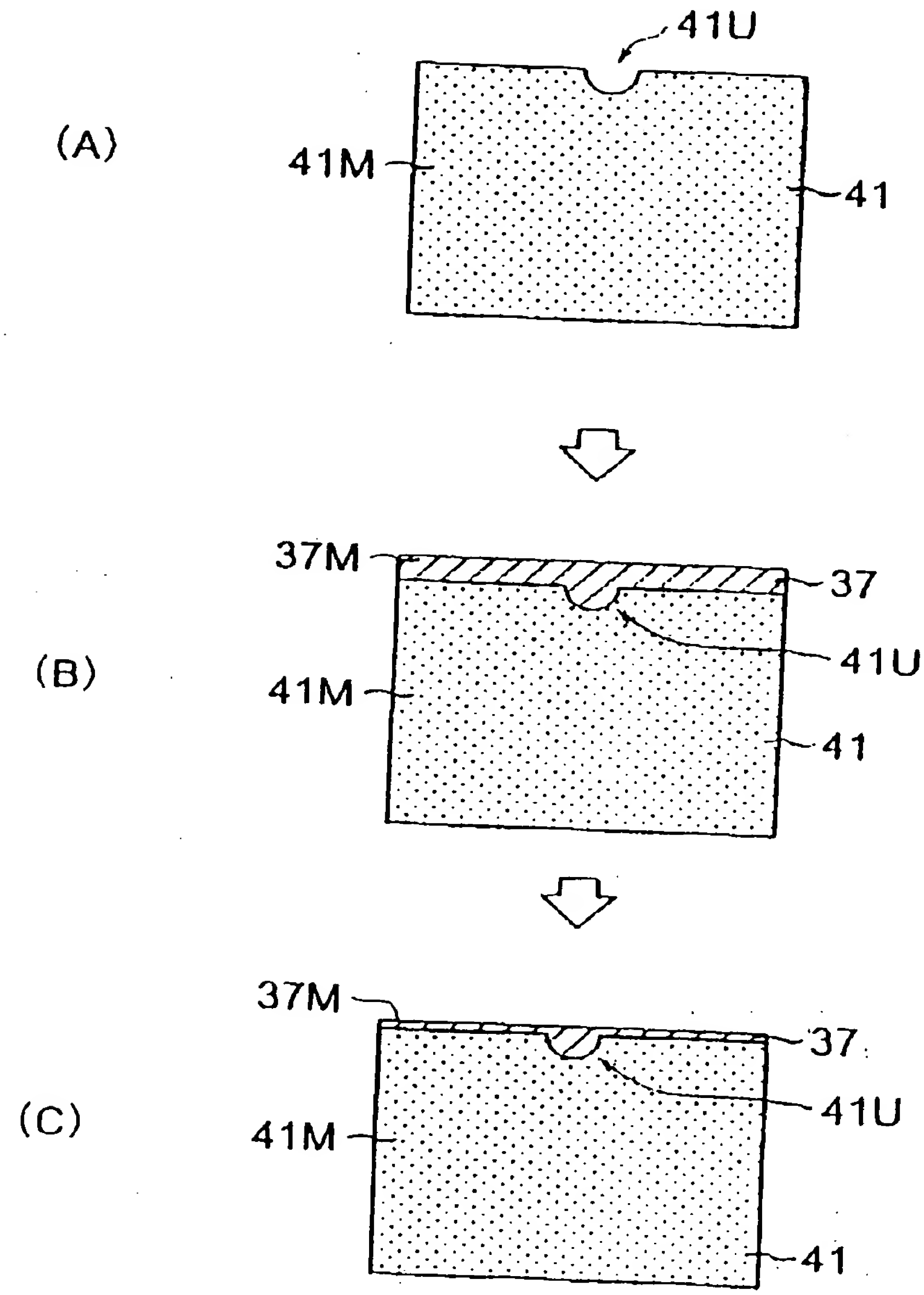


Fig. 15

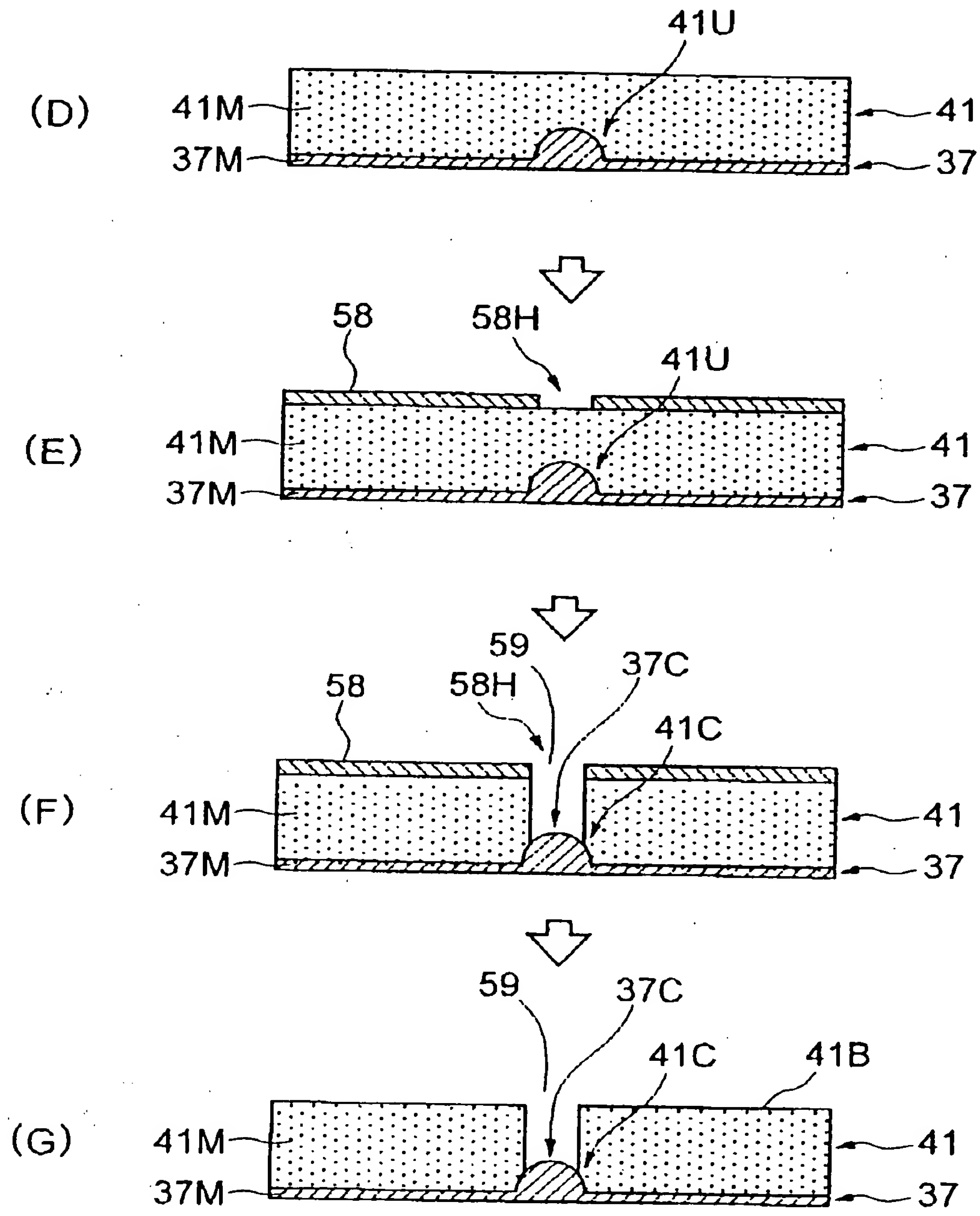

(D)
41U
41M
37M
41
37
(E)
58
58H
41U
41M
37M
41
37
(F)
59
37C
58
58H
41C
41M
37M
41
37
(G)
59
37C
41C
41B
41M
37M
41
37

Fig. 16

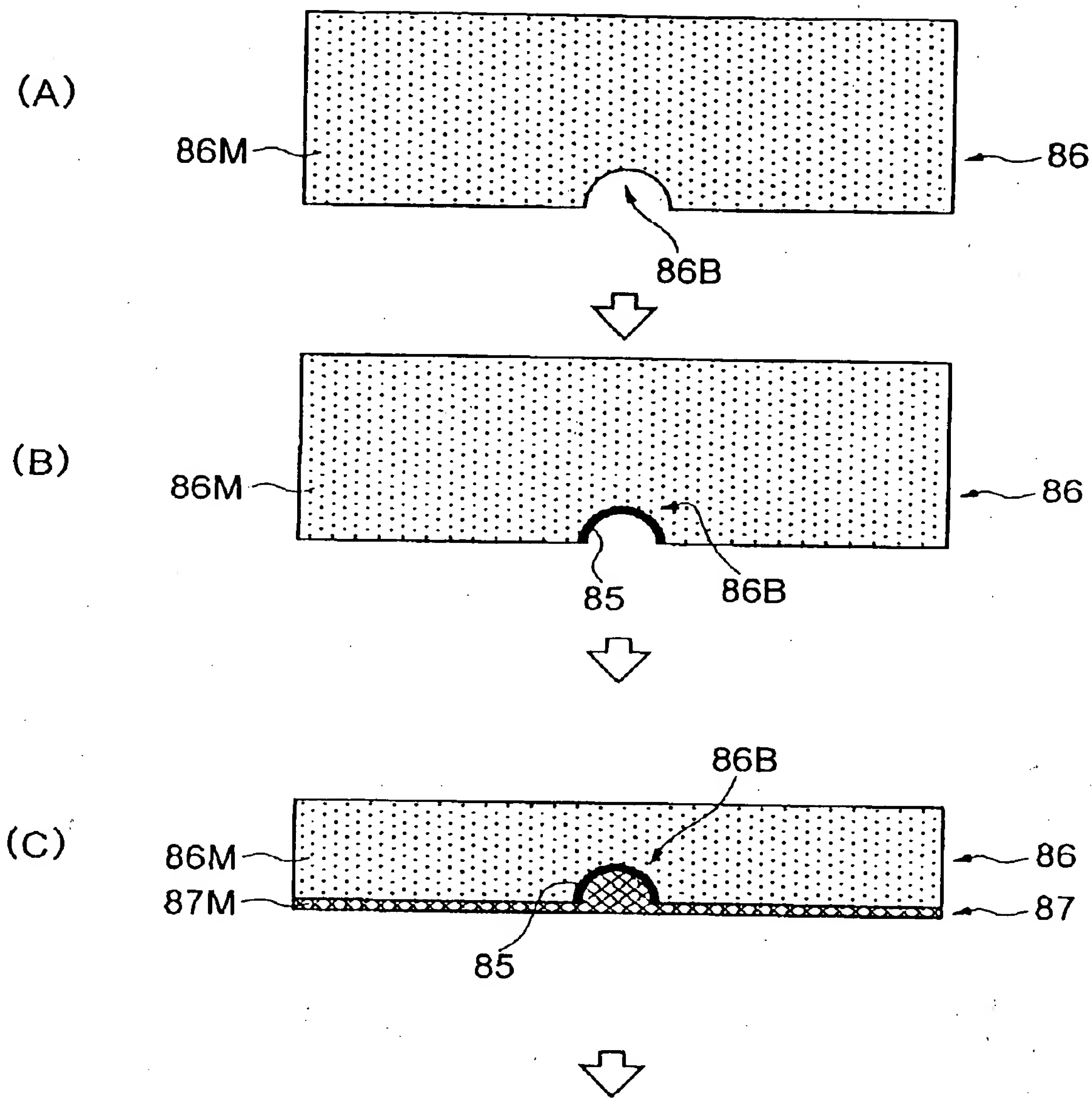


Fig. 17

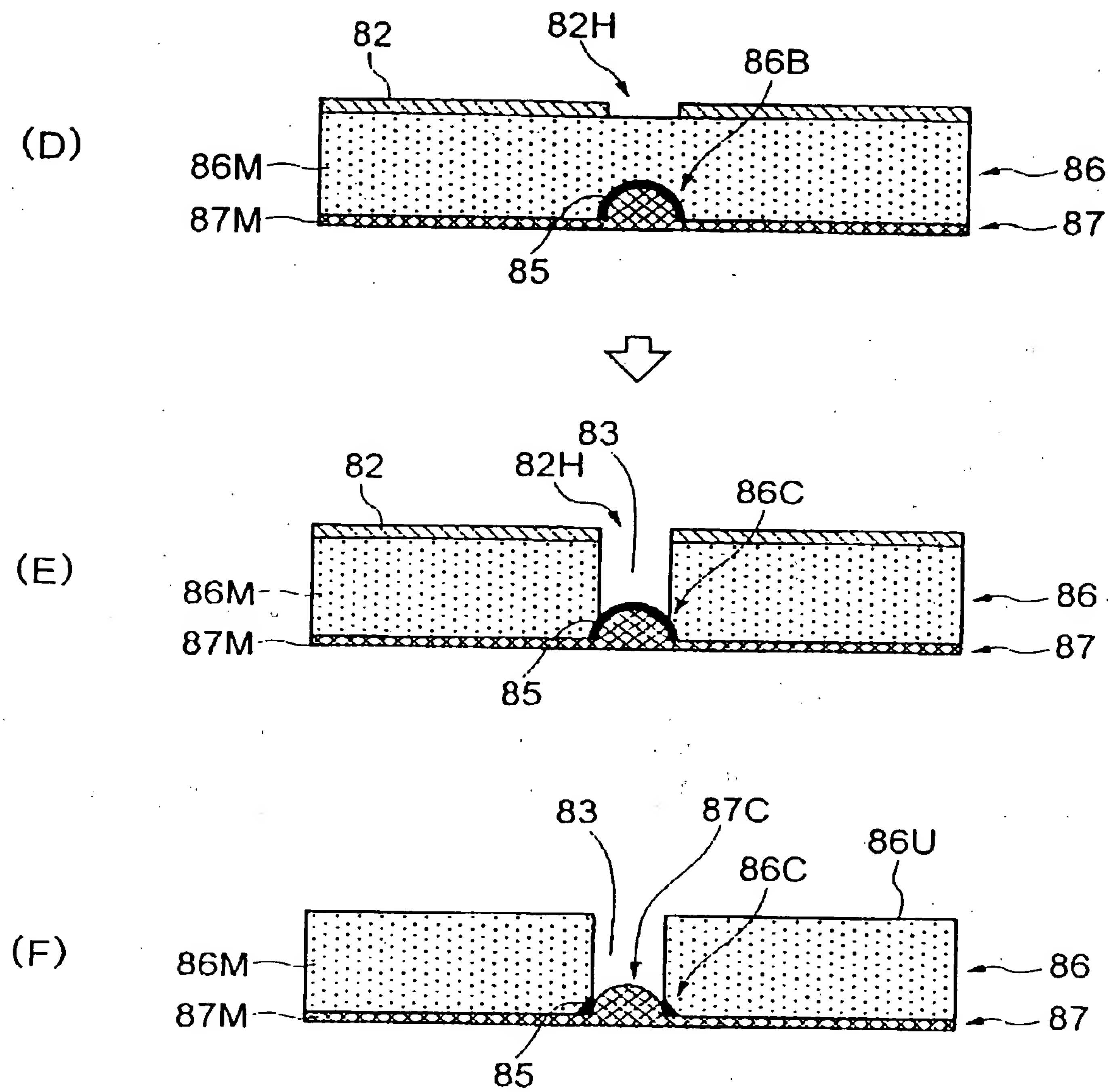

(D)
82
82H
86B
86M
87M
86
87
85
(E)
83
82
82H
86C
86M
87M
86
87
85
(F)
83
87C
86U
86C
86M
87M
86
87
85

Fig. 18

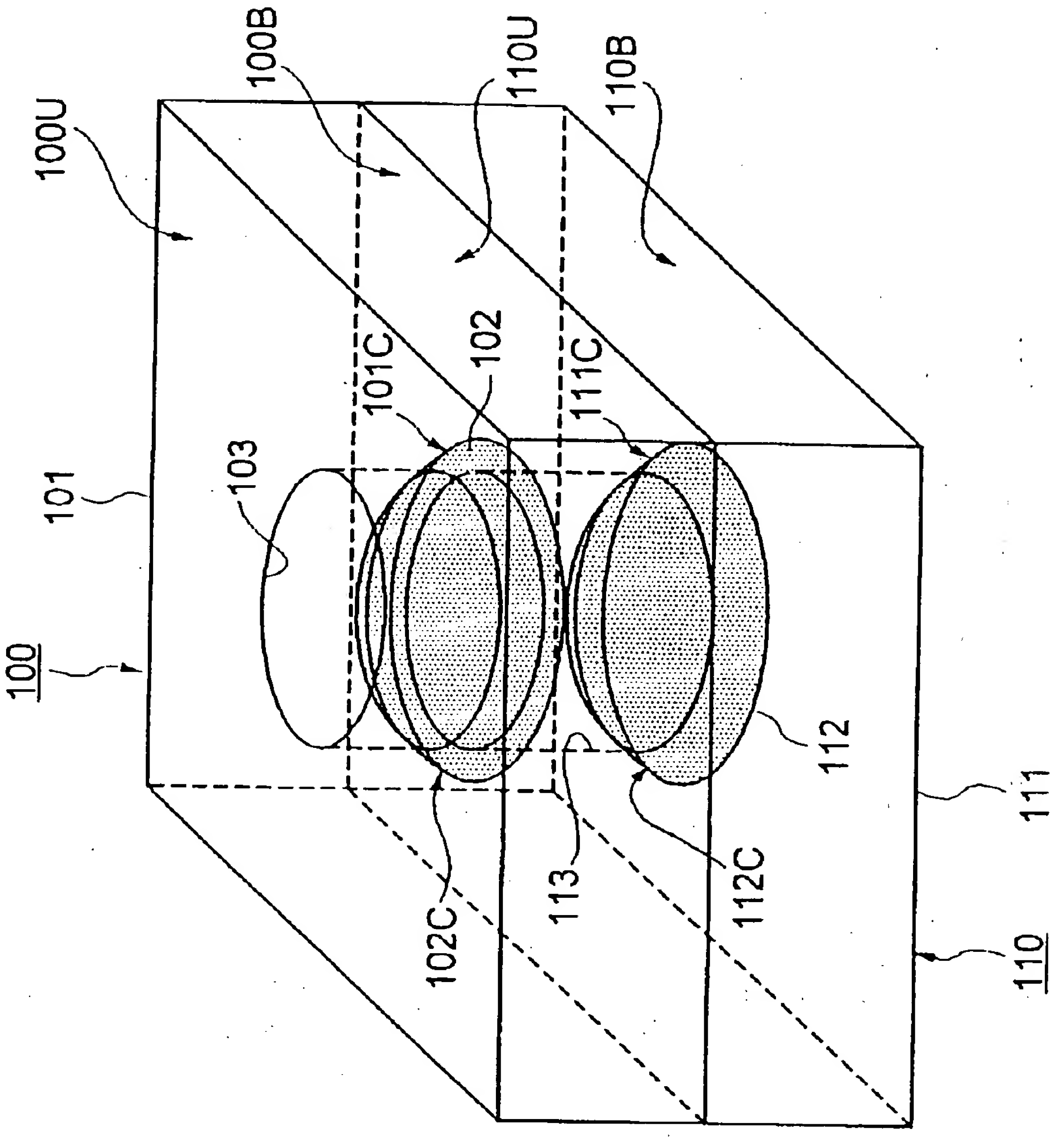

100U
100B
110U
110B
101C
102
111C
103
101
119
100
112
111
113
112C
102C
110

Fig. 19

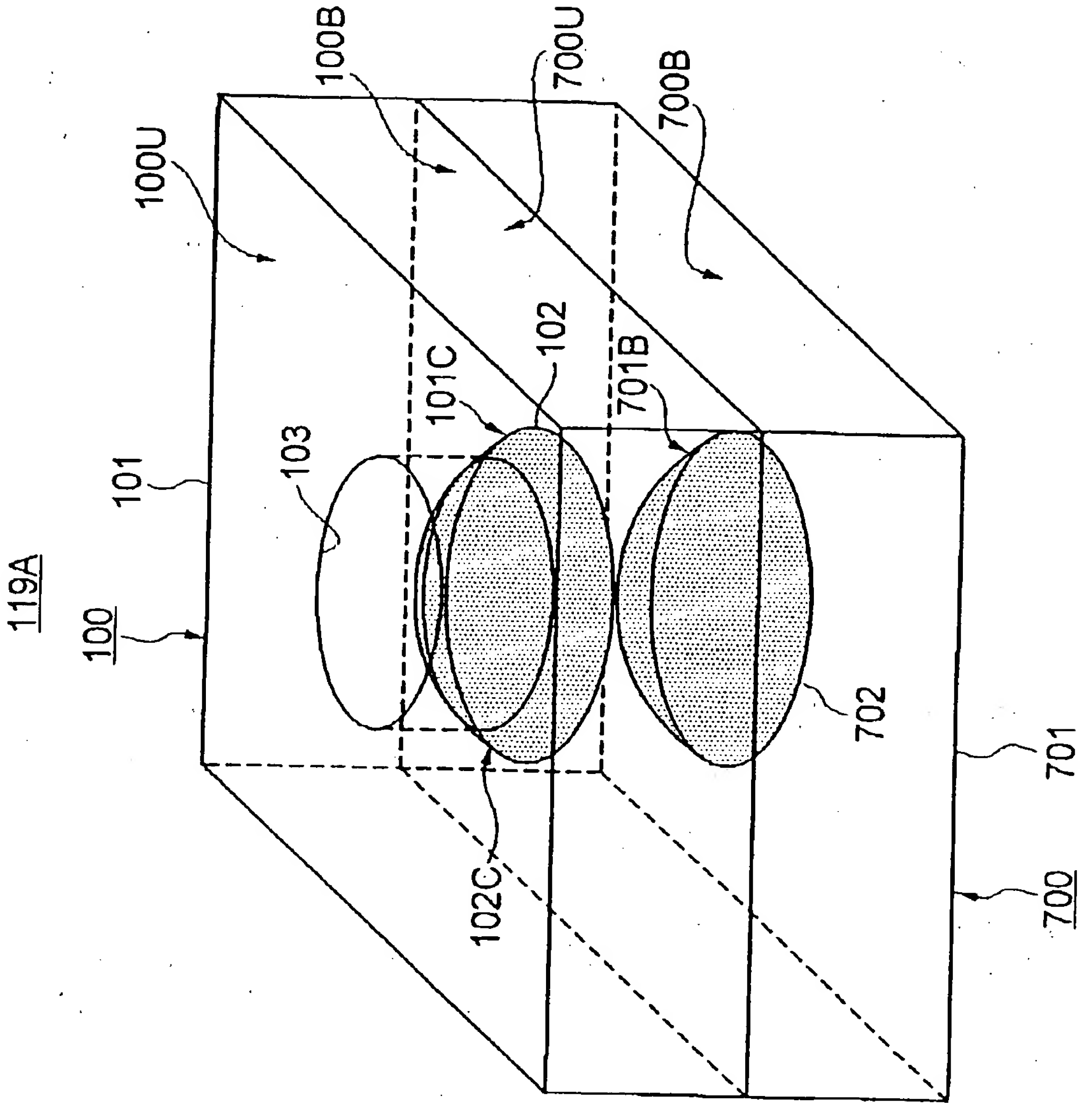

119A
100
101
103
100U
100B
700U
700B
101C
102
701B
102C
702
701
700

Fig. 20

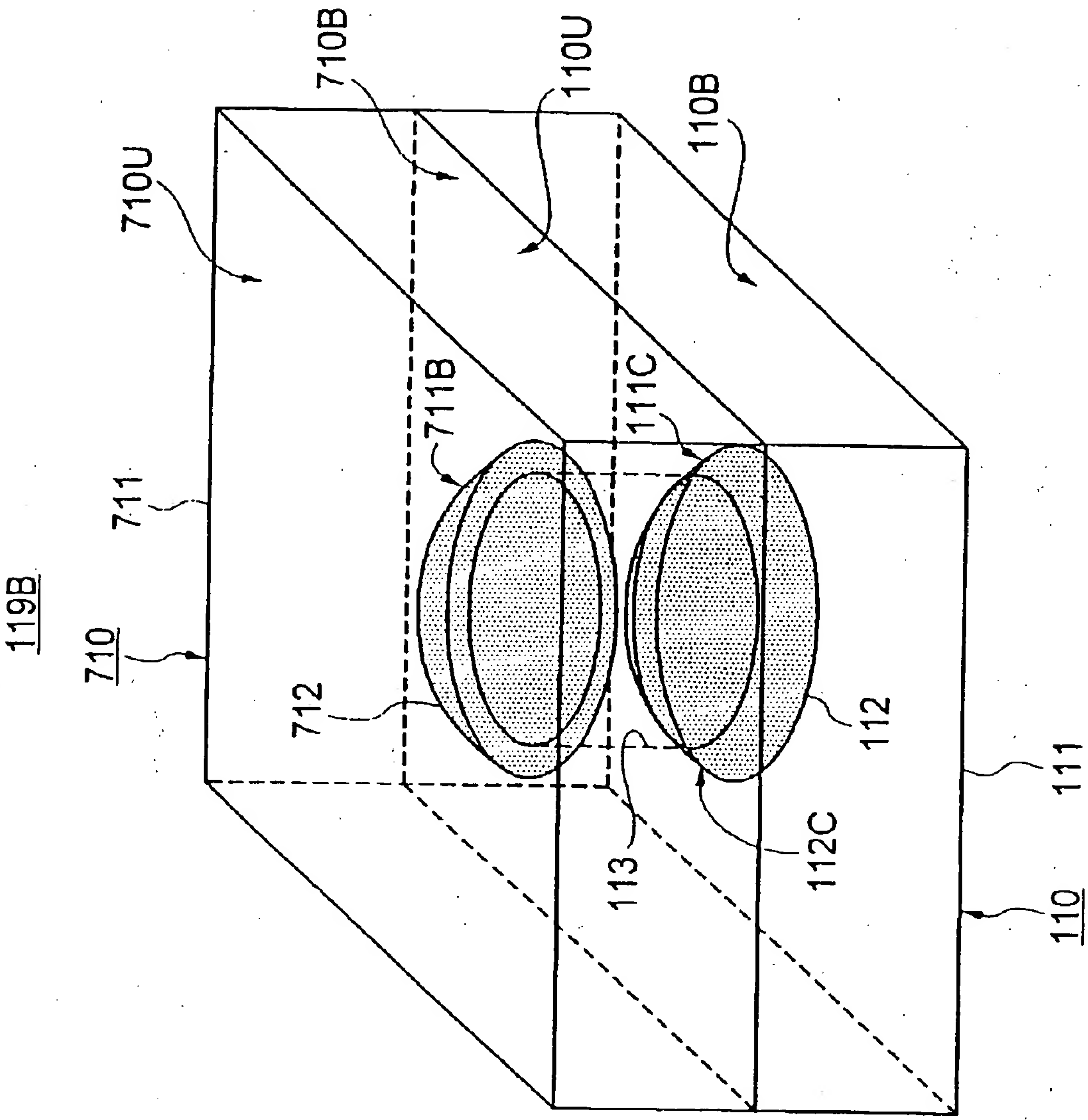

119B
710
711
710U
710B
110U
110B
711B
111C
712
112
111
112C
113
110

Fig. 21

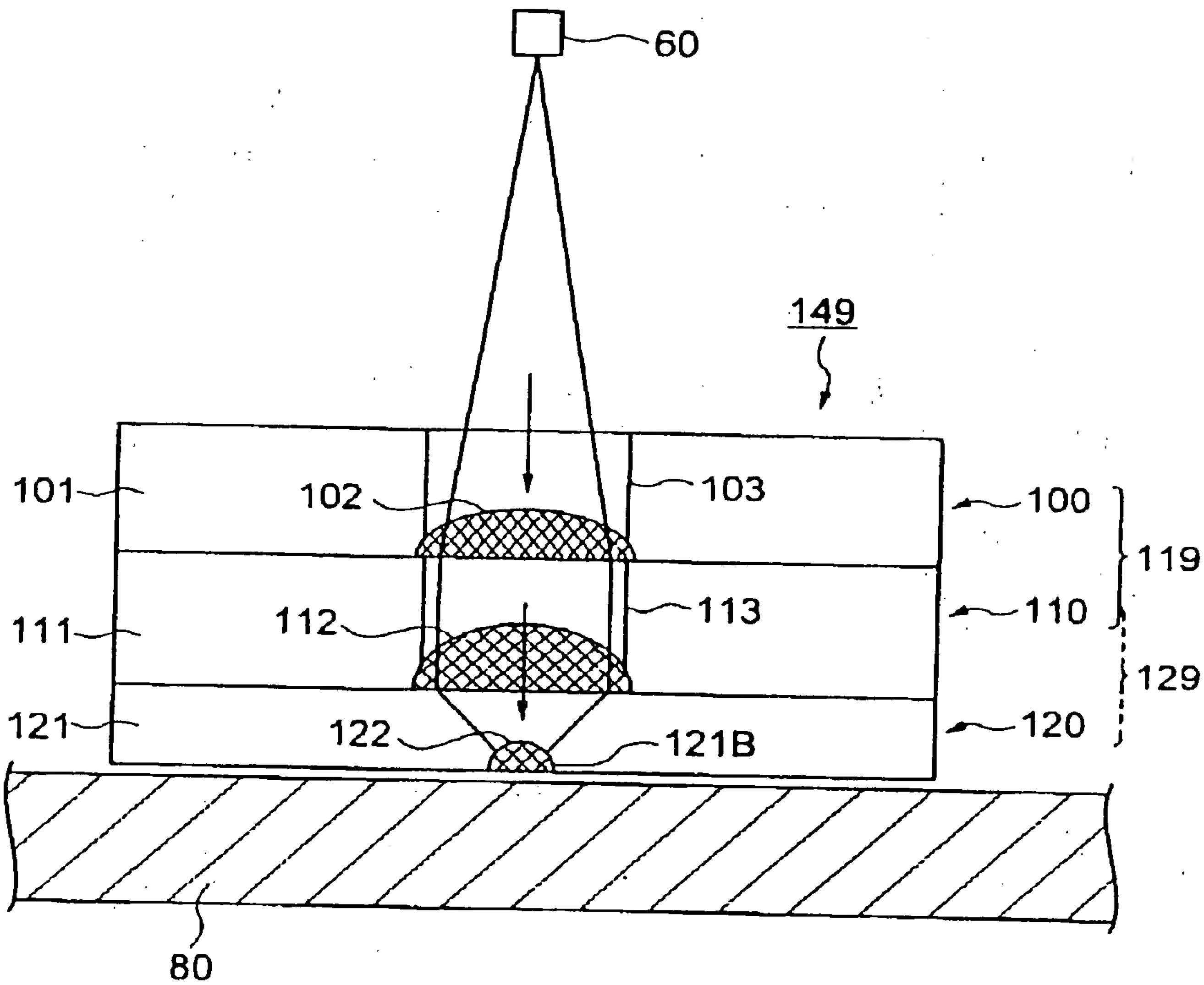

60
149
101
102
103
100
119
111
112
113
110
129
121
122
121B
120
80

Fig. 22

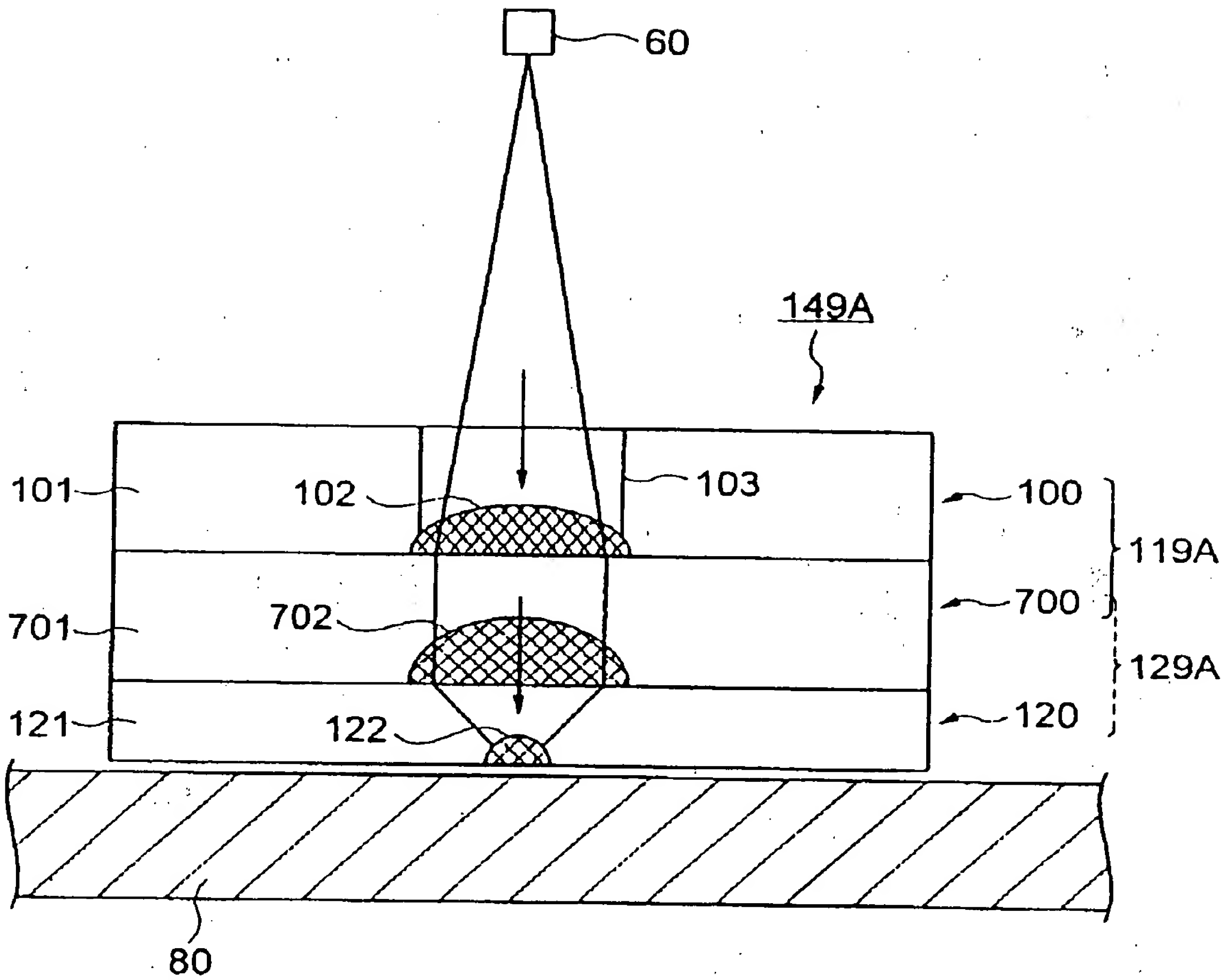


Fig. 23

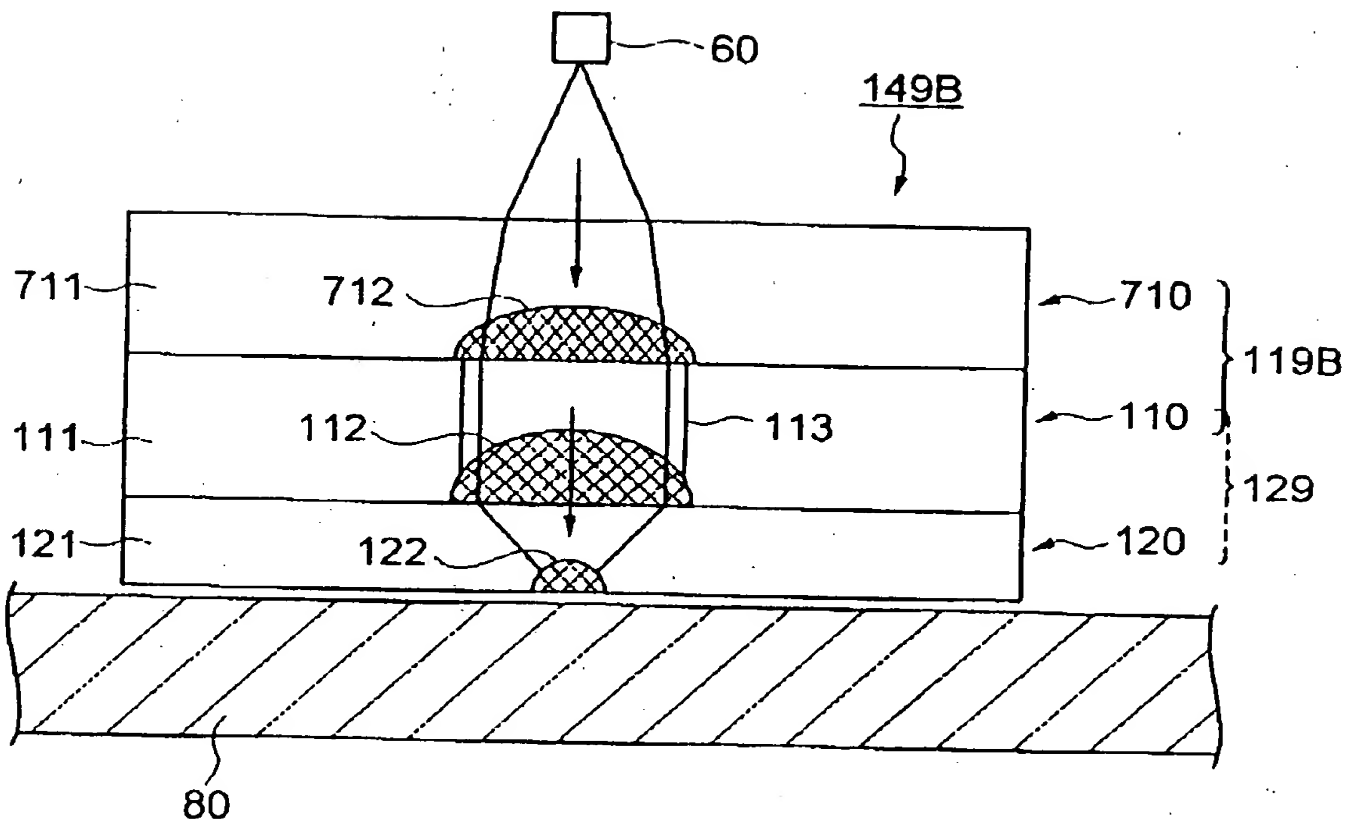


Fig. 24

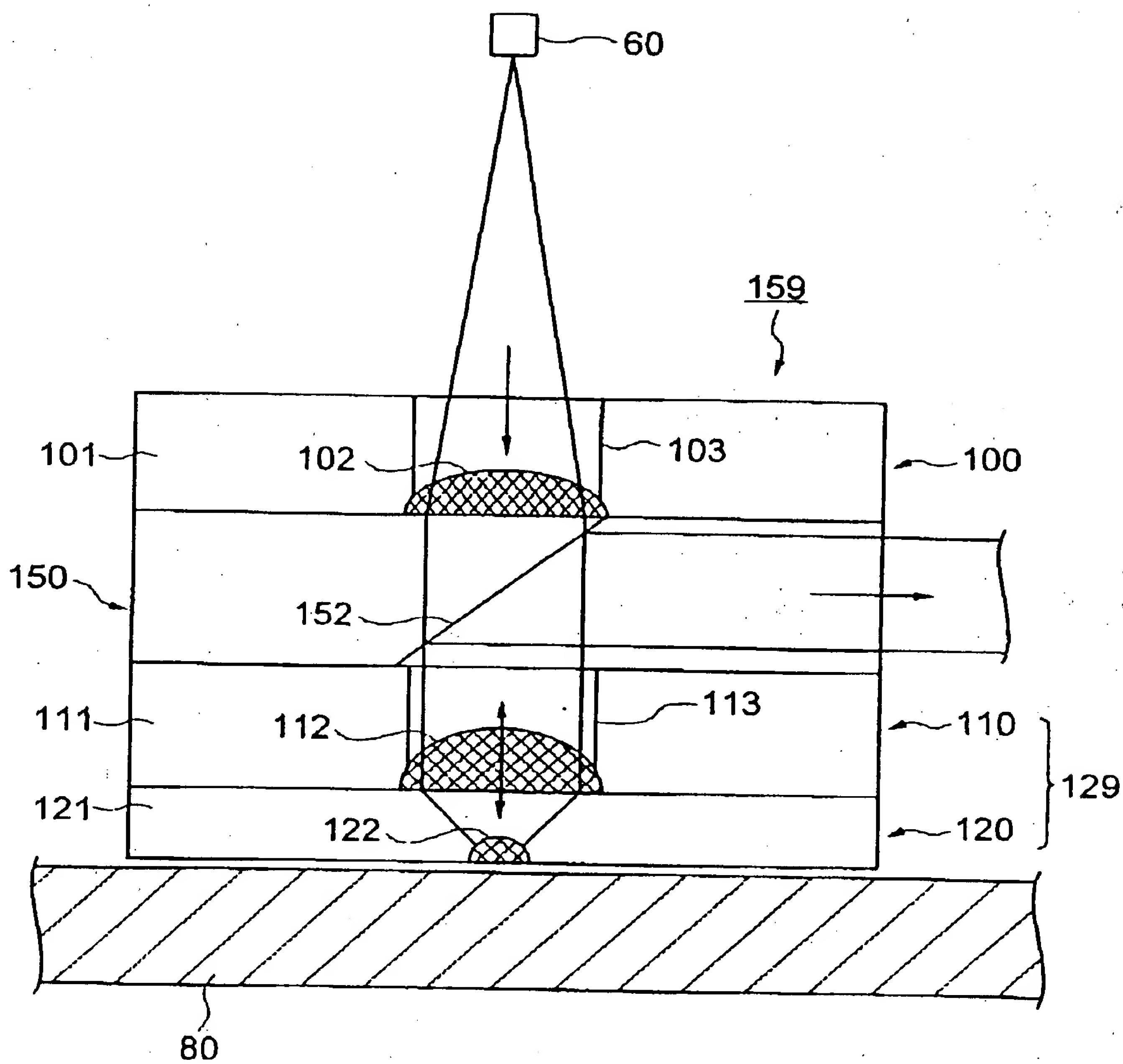


Fig. 25

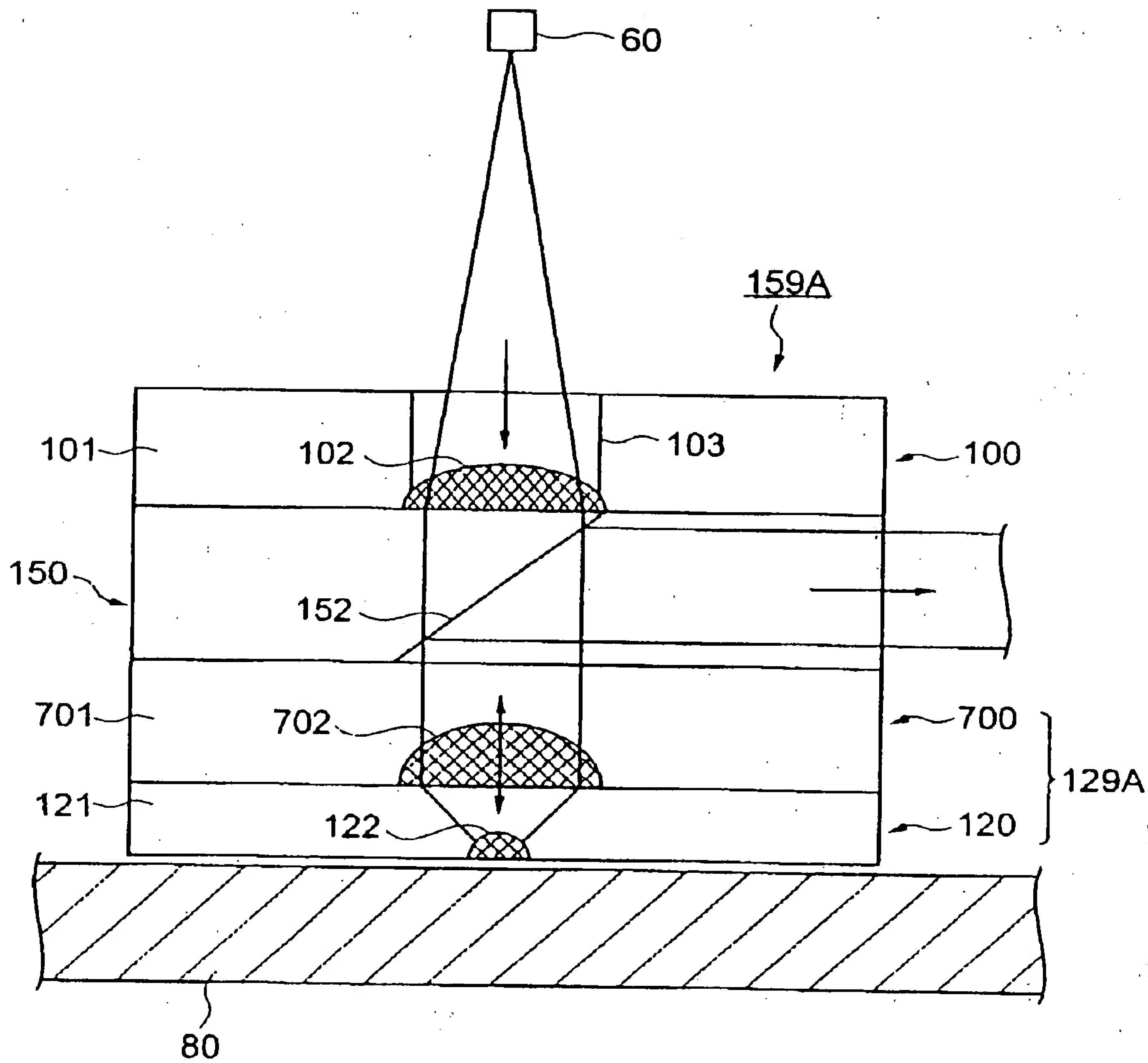


Fig. 26

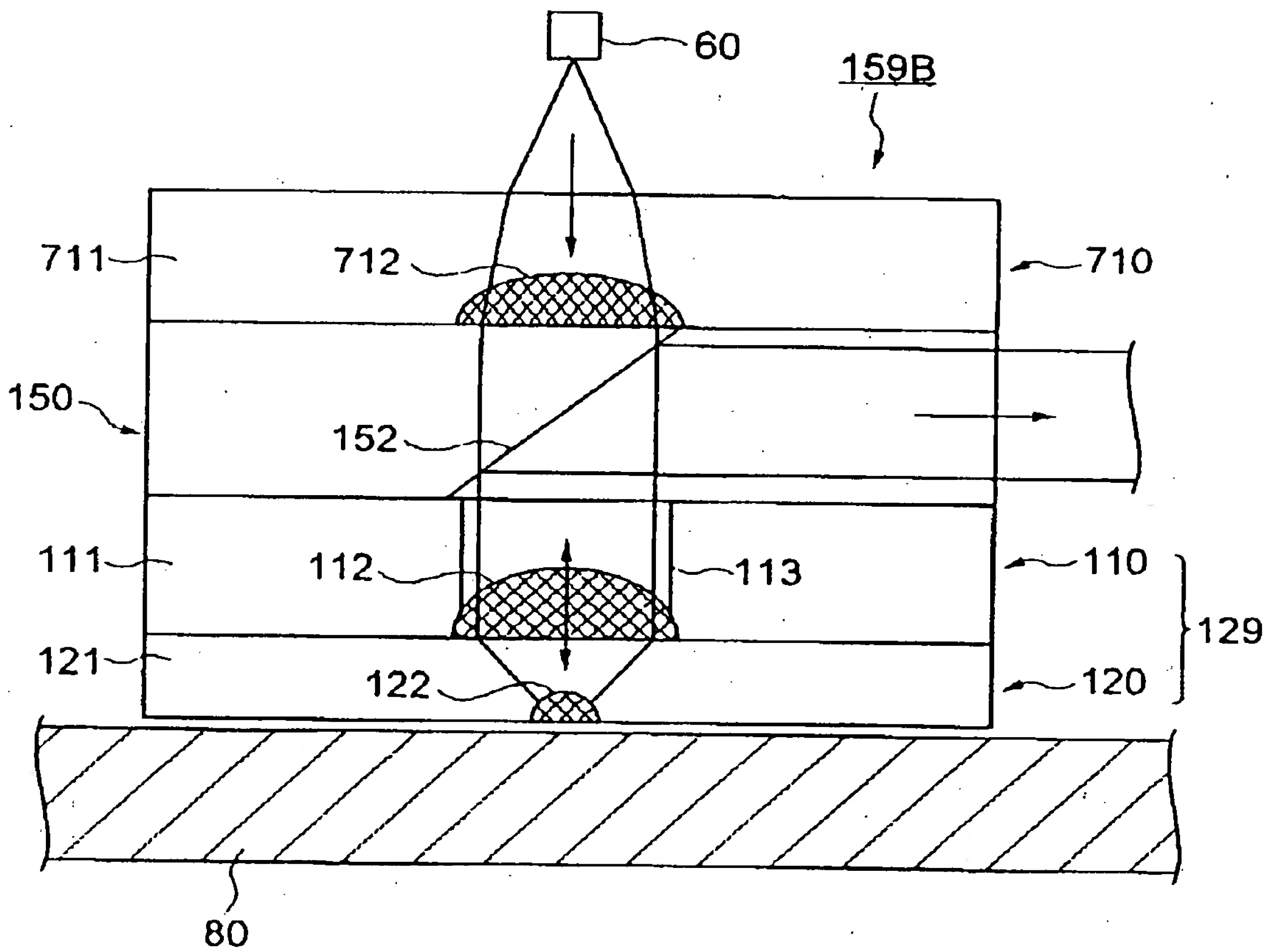


Fig. 27

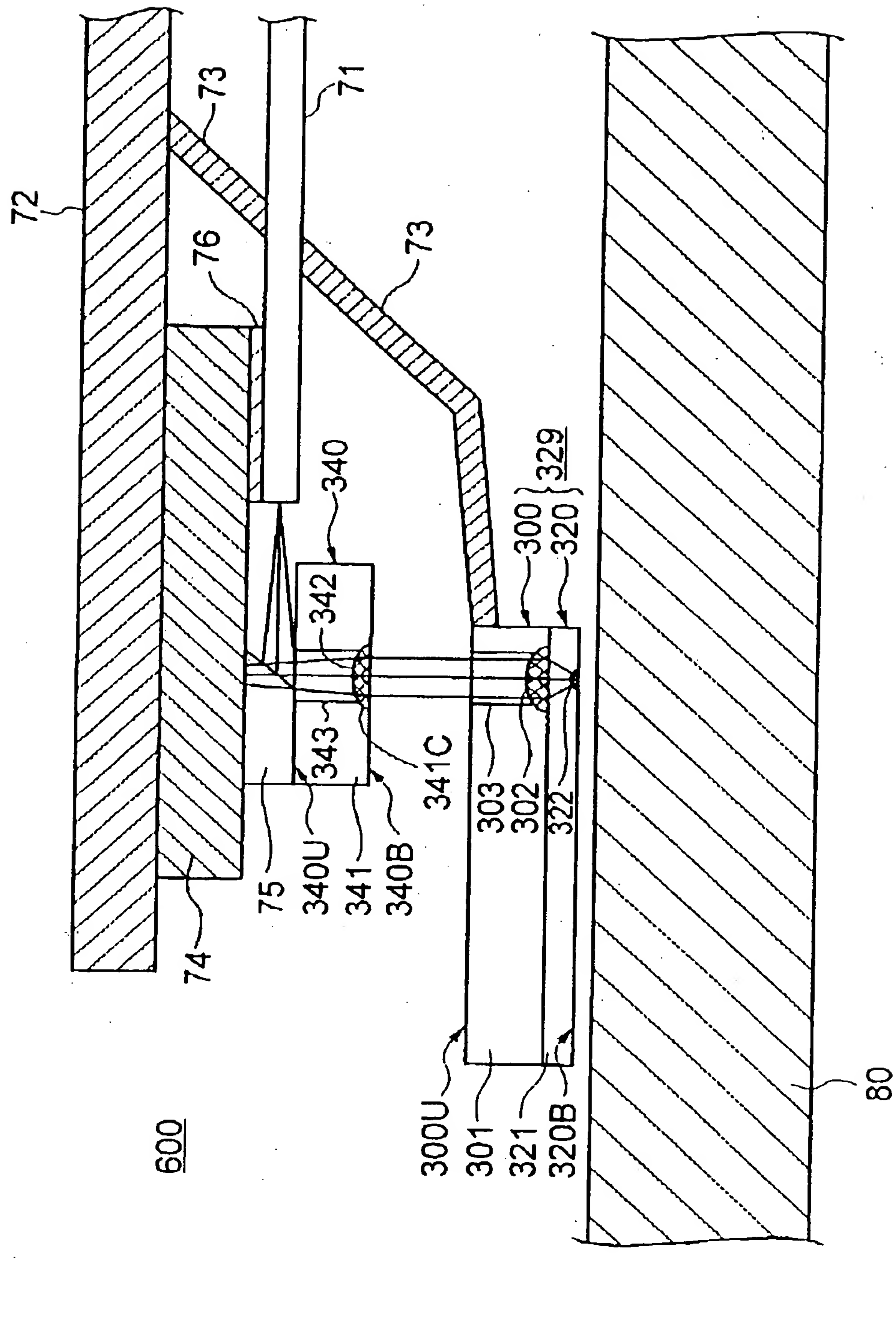

71
72
73
73
76
76
74
75
340
342
343
341C
340U
341
340B
329
300
320
303
302
322
300U
301
321
320B
80
600

Fig. 28

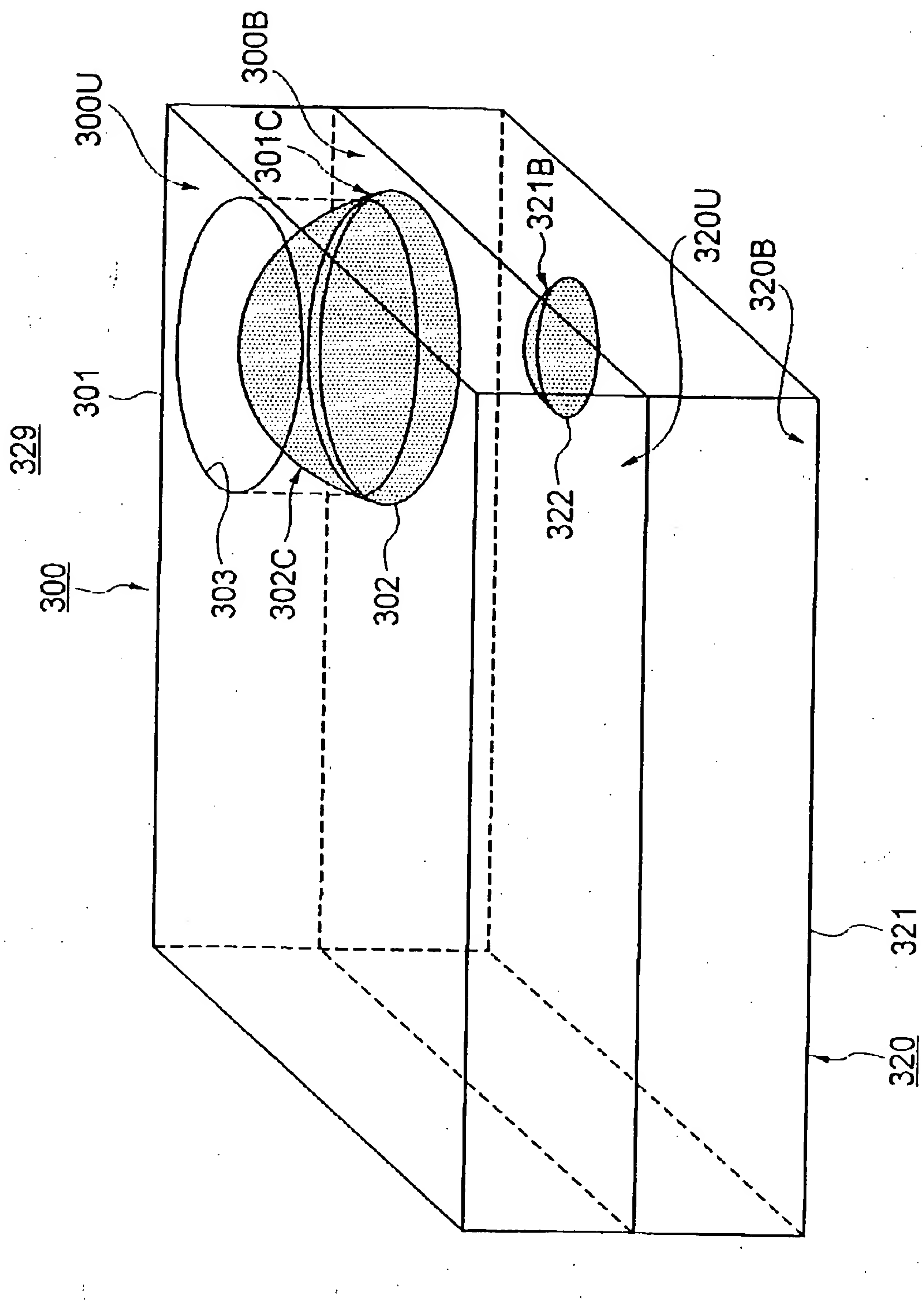
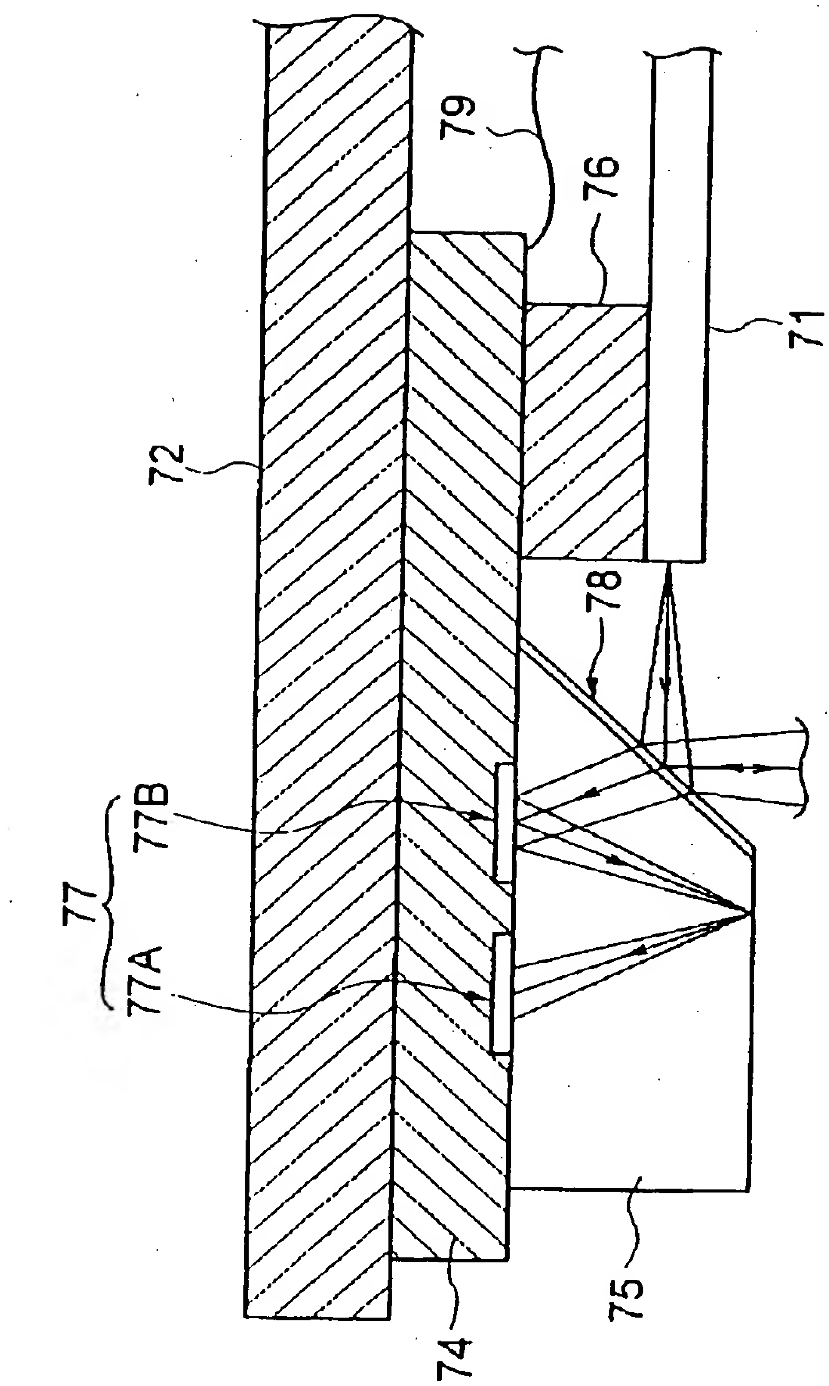

300U
300B
301C
321B
320U
320B
329
301
300
303
302C
302
322
321
320

Fig. 29



[NAME OF DOCUMENT] Abstract

[ABSTRACT]

[PROBLEM] To provide an optical device having a convex lens with a small size and a large numerical aperture.

[SOLVING MEANS] An optical device 100 has a convex lens 102 with a convex curved face 102C formed therein and a base material 101 closely contacting the convex curved face 102C of the convex lens 102. The base material 101 has first and second faces 100U and 100B facing each other, a concave curved face 101C closely contacting the convex curved face 102C is formed in the first face 100B, and a hole 103 communicating to the second face 100U is formed from a deep side of the concave curved face 101C. The center portion of the convex curved face 102C of the convex lens 102 is exposed in the hole 103 of the base material 101. For example, by filling an optical material in the concavity of the base material to form the convex lens 102 and providing the hole 103 in the base material with the convex lens 102 formed thereon, it is possible to manufacture the optical device 100. By reducing the size of the concavity of the base material filled with the optical material, it is possible to reduce the size of the convex lens 102 of the optical device 100.

[SELECTED DRAWING] Fig. 1